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Department of Water Resources

SALINITY INCURSION AND WATER RESOURCES

APPENDIX to BULLETIN No. 76

DELTA WATER FACILITIES

Preliminary Edition

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APRIL 1962

EDMUND G. BROWN
Governor
State of California

WILLIAM E. WARNE
Administrator
The Resources Agency of California
and Director
Department of Water Resources

State of California
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STATEMENT OF CLARIFICATION

This preliminary edition presents a comparison of alternative solutions to the Delta problems. This bulletin shows that the Single Purpose Delta Water Project is the essential minimum project for successful operation of the State Water Facilities. This bulletin also presents, for local consideration, optional modifications of the Single Purpose Delta Water Project which would provide additional local benefits.

The evaluation of project accomplishments, benefit-cost ratios, and costs of project services, are intended only to indicate the relative merits of these solutions and should not be considered in terms of absolute values. Benefits related to recreation are evaluated for comparative purposes. Detailed recreation studies, presently in progress, will indicate specific recreation benefits.

Subsequent to local review and public hearings on this preliminary edition, a final edition will be prepared setting forth an adopted plan. The adopted plan will include, in addition to the essential minimum facilities, those justifiable optional modifications requested by local entities.

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FOREWORD

This appendix to Bulletin No. 76, "Delta Water Facilities", is one of six appendices upon which were based the recommendations and conclusions in Bulletin No. 76. Other appendices are entitled:

Economic Aspects

Delta Water Requirements

Recreation

Plans, Designs, and Cost Estimates

Channel Hydraulics and Flood Channel Design

Data and analyses contained in this appendix were utilized to determine the present and future quantity and quality of water supplies within the Delta and to determine the conditions under which the State Water Facilities must operate within the Delta with the various facilities proposed in Bulletin No. 76 constructed therein. In general, the conditions imposed result from conservative assumptions of available water supply and Delta channel hydraulics.

Since Bulletin No. 76 is a preliminary draft designed to assist local agencies in evaluating the means by which local Delta problems can be solved within the structure of the State Water Resources Development System, all conclusions presented in this appendix must be considered preliminary. Following local review and public hearings on Bulletin No. 76, a final report will be issued, which will incorporate comments and suggestions pertinent to the appendices as well as the summary report. The final report will describe the essential minimum facilities and those economically justifiable options requested by local interests.

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CHAPTER I. INTRODUCTION

This appendix report substantiates and supplements the findings, conclusions, and recommendations regarding salinity incursion and water resources summarized in Bulletin No. 76, entitled "Delta Water Facilities". It encompasses the engineering studies on these subjects conducted pursuant to the Abshire-Kelly Salinity Control Barrier Acts of 1955 and 1957, and legislation enacted in 1959 to investigate water supplies and flood control levees for the Sacramento-San Joaquin Delta. Back-up data for this report are compiled in several volumes entitled "Back-up Data", for "Salinity Incursion and Water Resources Appendix to Bulletin No. 76". These data are too voluminous for general distribution, so are on file with the department and available in Sacramento for examination or reference.

Delta Water Facilities

The alternative systems of works which comprise the Delta Water Facilities are summarized in Bulletin No. 76, "Delta Water Facilities". Plans for water salvage and transfer range from a physical barrier near the outlet of the Delta at Chipps Island, with only minor modifications to existing channels in the Delta, to a comprehensive multipurpose plan for the Delta water facilities. The Chipps Island Barrier Project involves little change in the Delta channels but would create a fresh-water system of waterways and eliminate the present tidal flows above the barrier when the barrier gates are closed. The Comprehensive Delta Water Project would extensively alter the network of channels in the Delta by creating closed nontidal networks of fresh-water channels isolated from the remaining network of channels subject to tidal flows. The other two systems of works; the Single Purpose and Typical

Alternative Delta Water Projects are primarily modifications of the Comprehensive Delta Water Project, with features for flood control and other functions eliminated or reduced in scope.

Purpose of Studies

The purpose of these studies were severalfold: (1) to determine the relationship of salinity incursion into the Delta to the fresh-water outflow therefrom; (2) to determine the minimum outflow of fresh water from the Delta to Suisun Bay necessary to operate the Delta water facilities; (3) to determine the outflow from the Delta to enable future rates of export from the Delta with and without facilities constructed therein; (4) to determine past, present, and future salinity conditions in channels of the western Delta; and (5) to determine the quantity and quality of water supplied to and exported from the Delta for several conditions of development.

Scope of Studies

Salinity incursion studies encompassed (1) analysis of historical salinity and streamflow records to find the relationship of sea water incursion from the upper San Francisco Bays into the channels of the Delta to the fresh-water outflow from the Delta, (2) review of the findings of Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and upper San Francisco Bay" (Reference 8), and (3) trials of other approaches to mathematically relate salinity incursion to Delta outflow.

Field programs were undertaken to provide information lacking in the available data. As a result, field measurements were various and covered seemingly widely different programs. Collectively however, they were pointed toward the one objective, better understanding of the phenomenon of the mixing of fresh and saline waters in the San Francisco Bays and Delta so that a reliable prediction of future salinity conditions could be made. Field programs included: (1) salinity measurements in other tidal rivers of the State; (2) tidal flow and salinity measurements at the levee breaks of lower Sherman Island; (3) simultaneous salinity and current velocity measurements throughout the western Delta and Suisun Bay; and (4) salinity gradient observations in the upper bays and Delta. These programs are not discussed in detail in this report, but the data collected, analyses made of the data, and a discussion of the programs, are on file in the "back-up" data.

Service agreements for studies of tidal conditions under project conditions conducted on an electronic analog model of the San Francisco Bay and Delta systems, and programming of sea water incursion routing studies on an electronic digital computer were issued to the University of California at Berkeley and Stanford University at Palo Alto, respectively. Services were also obtained from consulting engineers on specific problems needing special attention and analysis.

Water resources available to the Delta were determined for past, present, and future conditions of development in the drainage areas tributary to the Delta on the Basis of a 20-year water supply equivalent to that of the water years 1921-22 through 1940-41. In addition to computing stream flow entering the Delta for this water supply period of past, present, and future conditions, historical stream flow entering the Delta for 1921-22 through 1956-57 water years was also determined. Estimates were made of Delta outflow to protect water exported from and used in the Delta for all conditions of development with and without facilities proposed therein.

The quality of water to be exported from the Delta and to be expected at various locations therein was estimated for conditions of development in the year 1990. These estimates were predicated on water- and salt-routing studies based on flow patterns with Delta water facilities in operation.

Area of Investigation

The area encompassed by the studies of water resources and salinity incursion included about all of the Central Valley, and the San Francisco Bay system, as delineated on Plate 1, "General Area of Investigation". Drainage areas contributing runoff to the Delta were included in the study because they affect the supply of water to the Delta. The San Francisco Bay system is naturally a part of any study of sea water incursion in the Delta because it is the tides in the Pacific Ocean which cause the huge volumes of water to move through the Golden Gate into the San Francisco Bay system and Delta to create the salinity incursion problem.

The one specific area of investigation, of course, is the Sacramento-San Joaquin Delta, and the western Delta study area, a part of which is outside the legally defined Delta. The boundaries of the legally defined Delta, the western Delta study area, and Delta lowlands, are shown on Plate 2, "Areas of Investigation, Sacramento-San Joaquin Delta".

Related Studies and Reports

In the course of this investigation considerable use was made of studies and reports of other units in the department. Reference was also made to many other publications on subjects related to salinity incursion, mixing of fresh and saline waters, hydrology of the Delta and Central Valley, and tidal hydraulics. Reference material used in the course of these studies is listed at the back of the report under "References". When attention is called to a particular reference in the text, the number of the reference is noted.

CHAPTER II. DELTA CHANNEL HYDRAULICS

Hydraulics of the Delta channels entail consideration of both tide and stream flow. Both factors affect the distribution and magnitude of flows through the many sloughs and channels of the Delta. Although flows in all channels of the Delta have not been related to various tidal and Delta inflow conditions or to flows in other channels, flows in some of the principal channels have been. The relationships determined are empirical, based upon field measurements and observations of tide and flow. Mathematical expressions of flows in many channels were not derived because of the complexity of the channel regimen, for example, multiplicity of channel interconnections, nonuniformity of channel cross sections, meanderings of the channels, and the unsteady flow in the channels.

In this chapter the flows of water in channels of the Sacramento-San Joaquin Delta are described to give an insight of the complexity of the area, which is the hub of The California Water Plan. Tide and flow conditions in some of the more important channels of the Delta are also discussed.

Sacramento-San Joaquin Delta

The Sacramento-San Joaquin Delta lies at the confluence of the Sacramento and San Joaquin Rivers which drain the Central Valley of California. The Sacramento River drains the Sacramento River basin in the northern part of the valley. The San Joaquin River drains the San Joaquin drainage basin in the southern part of the Central Valley. These two rivers unite near the City of Pittsburg, approximately 50 miles east of San Francisco, turn westward and discharge their flows by way of Suisun, San Pablo, and San Francisco Bays into the Pacific Ocean. The Delta extends from the vicinity of Pittsburg to Sacramento on the north, Stockton on the east, and Tracy on the south. It is interlaced with 700 miles of interconnected channels which form more than 50 separate islands. The majority of the islands are below sea level and require high levees around them to prevent inundation. These islands have been reclaimed to form a rich agricultural area which contributes greatly to the economy of California.

Flow from the Sacramento River and the Yolo Bypass enter the Delta from the north and continue southward by several channels to unite with the flow from the San Joaquin River. Flow from the San Joaquin River enters the Delta from the south and proceeds through its branch channels to combine with the flow of the Sacramento River at the western end of Sherman Island. Entering the Delta from the east are the Cosumnes, Mokelumne, and Calaveras Rivers, French Camp Slough, Dry Creek, and smaller streams.

Entering the Delta from the west are several small streams, the most important of which is Putah Creek. These streams discharge their flows into channels in the Yolo Bypass and/or channels of the Cache Slough complex. These waters mix with the waters in the Delta channels, and the flows not consumed within the Delta or exported therefrom, eventually exit from the Delta toward the ocean via the confluence of the Sacramento and San Joaquin Rivers.

The Delta is traversed by two deep water channels; one leads to the Port of Stockton, and the other, now under construction will lead to the Port of Sacramento. Many other Delta channels are used for commercial tug and barge traffic. Due to the numerous sloughs, along which one may enjoy excellent sport fishing, the Delta channels have developed into a much-favored and highly used recreational area.

In summer months flows through the Delta channels are relatively small. During winter months flows are considerably larger, up to 700,000 second-feet during periods of extreme floods. Periods during which water is transferred across the Delta for export are the primary concern of this chapter. Flood flows are considered in the office report entitled, "Channel Hydraulics and Flood Channel Design".

Tidal Conditions in Delta Channels

Tides in the Delta are the result of tides in the Pacific Ocean. The tides in the Delta are not true tides but are periodic water surface fluctuations resulting from upstream movement of the progressive wave from the Pacific tides. The tidal wave moves in from the ocean through the Golden Gate into San Francisco Bay, then into San Pablo Bay, through the Carquinez Strait into Suisun Bay, and thence into the Delta channels. During periods of low river discharge the progessive waves continue northward up the Sacramento River and its branch channels until they are dissipated above Sacramento. The waves also continue up the San Joaquin River and its many branch channels in the southern portion of the Delta until dissipated south of Mossdale, about 20 miles south of Stockton. The rate of translation of the waves for the different tidal phases is not constant, but varies depending upon the phase of the true tides outside the Golden Gate, channel characteristics, and local meteorological conditions. A tidal phase is described as a particular level of tidal waters which recurs at fairly regular intervals. In the Delta, as well as on the Pacific Coast, these tidal phases, or levels, are designated as lower low, low high, high low, and higher high. The sequence of occurrence is generally in the order noted, and the interval between tidal phases is about 6 hours and 12 minutes.

High and low waters in the Delta occur semidiurnally and reflect the mixed type of tides that take place in the ocean along the Pacific Coast. The mixed tides along the Pacific Coast consist of two high and two low waters each lunar day (approximately 24 hours and 50 minutes), with generally marked differences in water elevations between the two high and the two low waters. The highest point of each tide depends upon astronomical and meteorological conditions. The characteristics of the coast and geography of the Bay system also play their parts in determing the tidal conditions in the Delta.

The waves resulting from the tides in the ocean progress upstream from the Golden Gate into the Delta taking approximately 10 to 13 hours to reach the uppermost points. As the tidal phases are approximately 6 hours and 12 minutes apart, the tide may be both rising and falling concurrently at different locations in the San Francisco Bay and Delta estuary. As a result, the water surface elevation within the estuary always has some degree of slope at any particular time.

Because of the tidal conditions in the Delta channels, the regimen of flow is rather complicated. In the lower reaches considerable volumes of water move into and out of the Delta channels each day during the two flood and two ebb tides. The progressive wave often arrives at one end of a slough or channel before arriving at the other. As a result the water surface elevations vary at each end of the slough causing unsteady flow.

TABLE 1

Tide Gage Recorders
San Francisco Bay System and Sacramento-San Joaquin Delta Operations
During 1959

Recorder number	Recorder name Channel and location	Recorder ownership 2/	Elevation of staff zero	Latitude	Longitude	Range	Township
0	Golden Gate recorder - San Francisco Bay at the Presidio	USCE	8.60'	37^0 48'24"	122^0 27'54"	6W	1S
1	Dumbarton Bridge 1/ - San Francisco Bay at the bridge	USCE	5.06'	37^0 30'00"	122^0 07'18"	2W	5S
2	San Mateo Bridge 1/- San Francisco Bay at bend in bridge	USCE	4.52'	37^0 34'42"	122^0 15'18"	3W	4S
3	Richmond Point 1/ - San Francisco Bay at Richmond Point	USCE	3.04'	37^0 54'30"	122^0 23'23"	5W	1N
4	San Pedro Point 1/ - San Pablo Bay at San Pedro Point	USCE	5.33'	37^0 59'18"	122^0 26'43"	5W	2N
5	Pinole Point 1/ - San Pablo Bay at Pinole Point	USCE	4.83'	38^0 00'54"	122^0 21'48"	4W	2N
6	Eckley 1/- Carquinez Straits at Eckley	USCE	4.54'	38^0 03'18"	122^0 12'06"	3W	2N
7	Martinez 1/ - Carquinez Straits at Martinez	USCE	1.80'	38^0 01'54"	122^0 07'42"	3W	2N
8	Nichols 1/ - Suisun Bay at Nichols	USCE	3.37'	38^0 03'12"	121^0 59'12"	1W	2N
9	Pittsburg 1/ - Sacramento River at Pittsburg	USCE	2.92'	38^0 02'36"	121^0 53'30"	1E	2N
10	Meins Landing 1/ - Montezuma Slough at Meins Landing	USCE	3.40'	38^0 08'24"	121^0 54'24"	1E	3N
11	Suisun Slough 1/ - Grizzly Bay at mouth of Suisun Slough	USCE	2.37'	38^0 07'18"	122^0 04'24"	2W	3N
12	Beldons Landing 1/ - Montezuma Slough at Beldons Landing	DWR	--	38^0 17'28"	121^0 43'29"	1W	4N
13	Peters Pocket 1/ - Confluence of Cache and Hass Sloughs	DWR	--	38^0 11'14"	121^0 58'17"	2E	5N
14	Steamboat Slough 1/ - Confluence of Steamboat and Sutter Sloughs	DWR	--	38^0 15'16"	121^0 35'54"	3E	5N
15	Georgiana Slough 1/ - Georgiana Slough, 1 mile north of railroad bridge	DWR	--	38^0 11'05"	121^0 33'52"	4E	4N

TABLE 1

Tide Gage Recorders
San Francisco Bay System and Sacramento-San Joaquin Delta Operations
During 1959 (continued)

Recorder number	Recorder name Channel and location	Recorder ownership 2/	Elevation of: staff zero	Latitude	Longitude	Range	Township
16	North Fork of Mokelumne River 1/ - North Fork of Mokelumne River 5 miles south of Walnut Grove	DWR	--	38^{0} 10'56"	121^{0} 31'37"	4E	5N
17	South Fork of Mokelumne River 1/ - South Fork of Mokelumne River opposite mouth of Hog Slough	DWR	--	38^{0} 09'53"	121^{0} 29'34"	5E	5N
18	Bishop and Rio Balanco Bridge 1/ - Bridge at mouth of Telephone Cut	DWR	--	38^{0} 04'22"	121^{0} 24'59"	5E	3N
19	Bacon Island ferry slip 1/ - Bacon Island ferry slip on Middle River	DWR	--	37^{0} 56'39"	121^{0} 31'54"	4E	1N
20	Twin Cities bridge - Snodgrass Slough at Twin Cities bridge	DWR	2.32'	38^{0} 35'19"	121^{0} 29'45"	4E	5N
21	I Street Bridge - Sacramento River at I Street Bridge	DWR	0.00'	38^{0} 35'10"	121^{0} 30'15"	4E	9N
22	Lisbon - Yolo By-Pass at Lisbon	DWR	0.00'	38^{0} 28'22"	121^{0} 34'50"	4E	7N
23	Clarksburg - Sacramento River at Clarksburg	DWR	0.00'	38^{0} 25'25"	121^{0} 31'42"	4E	7N
24	Snodgrass Slough - Sacramento River at Snodgrass Slough	DWR	3.02'	38^{0} 21'02"	121^{0} 31'56"	4E	6N
25	Liberty Island - Yolo By-Pass at Liberty Island	DWR	--	38^{0} 19'15"	121^{0} 40'00"	3E	6N
26	Lindsey Slough - Lindsey Slough near Yolo By-Pass	DWR	2.92'	38^{0} 14'45"	121^{0} 42'25"	2E	5N
27	Walnut Grove - Sacramento River at Walnut Grove	DWR	0.00'	38^{0} 14'22"	121^{0} 30'57"	4E	5N
28	New Hope - Mokelumne River at New Hope Landing	DWR	0.00'	38^{0} 13'36"	121^{0} 29'26"	4E	4N
29	Isleton - Sacramento River at Isleton	USBR	2.46'	38^{0} 09'46"	121^{0} 36'42"	3E	4N
30	Rio Vista - Sacramento River at Rio Vista	USCE	3.06'	38^{0} 08'42"	121^{0} 41'30"	2E	4N

TABLE 1

Tide Gage Recorders
San Francisco Bay System and Sacramento-San Joaquin Delta Operations
During 1959 (continued)

Recorder number	Recorder name Channel and location	Recorder ownership [2]	Elevation of staff zero	Latitude	Longitude	Range	Township
31	Georgiana Slough - confluence of Georgiana Slough and Mokelumne River	DWR	0.00'	38° 07'48"	121° 34'46"	3E	3N
32	San Andreas Landing - San Joaquin River at San Andreas Landing	DWR	2.84'	38° 06'12"	121° 35'26"	3E	3N
33	Threemile Slough - (Sacramento)- Threemile Slough at Sacramento River	DWR	10.00'	38° 06'18"	121° 41'57"	2E	3N
34	Threemile Slough - (San Joaquin)- Threemile Slough at San Joaquin River	DWR	10.00'	38° 05'13"	121° 41'07"	3E	3N
35	Collinsville - Sacramento River at Collinsville	DWR	3.05'	38° 04'25"	121° 51'18"	1E	3N
36	Venice - San Joaquin River on Empire Tract	DWR	3.45'	38° 03'01"	121° 29'45"	4E	2N
37	Antioch - San Joaquin River at Antioch water works intake	DWR	9.96'	38° 01'04"	121° 48'05"	2E	2N
38	Holland - Old River 1.5 miles south of northeast corner of Holland Tract	DWR	2.61'	38° 00'26"	121° 34'47"	4E	2N
39	Rock Slough - Rock Slough at Contra Costa Canal intake	DWR	--	37° 58'35"	121° 38'19"	3E	2N
40	Old River at Rock Slough - Old River 1.5 miles north of Rock Slough	DWR	3.00'	37° 59'21"	121° 34'51"	4E	2N
41	Bacon Island - Middle River at Connection Slough	DWR	2.94'	38° 00'07"	121° 31'22"	4E	2N
42	Rindge - San Joaquin River at Fourteenmile Slough	DWR	0.00'	37° 59'51"	121° 25'06"	5E	2N
43	Burns Cutoff - Stockton Ship Channel on Rough and Ready Island	DWR	3.02'	37° 57'46"	121° 21'54"	6E	1N

TABLE 1

Tide Gage Recorders
San Francisco Bay System and Sacramento-San Joaquin Delta Operations
During 1959 (continued)

Recorder number	Recorder name Channel and location	Recorder ownership [2]	Elevation of staff zero	Latitude	Longitude	Range	Township
44	Mansion House - Old River at Mansion House	DWR	0.00'	37° 54'37"	121° 33'39"	4E	1N
45	Middle River at Highway 4 - Middle River at Highway 4 bridge	DWR	0.00'	37° 53'28"	121° 29'20"	4E	1N
46	Brandt Bridge - San Joaquin River at Brandt Bridge	DWR	3.79'	37° 51'53"	121° 19'18"	6E	1S
47	Mowery Bridge - Middle River at Mowery Bridge	DWR	2.67'	37° 50'04"	121° 22'59"	5E	1S
48	Clifton Court ferry - Old River at Clifton Court ferry	DWR	2.12'	37° 49'28"	121° 33'05"	4E	1S
49	Grant Line Canal - Grant Line Canal at Tracy Road	DWR	2.13'	37° 49'13"	121° 26'58"	5E	1S
50	Mossdale Bridge - San Joaquin River at Mossdale Bridge	DWR	0.30'	37° 47'12"	121° 18'21"	6E	2S
51	Vernalis - San Joaquin River at Vernalis	DWR	0.00'	37° 40'31"	121° 15'57"	6E	3S
52	Benicia arsenal - Suisun Bay at Benicia arsenal wharf	DWR	0.00'	38° 02'34"	122° 08'00"	2W	2N
53	Old River - Old River at Tracy Road	DWR	--	37° 48'18"	121° 26'53"	5E	1S

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[1] Indicates temporary recorder.

[2] USCE - United States Corps of Engineers.
DWR - Department of Water Resources.
USBR - United States Bureau of Reclamation.

Although the tidal flows can be measured by standard metering methods, the computation of tidal or net flows through these sloughs by theoretical methods involve solving the unsteady flow equation, as shown on equation 112, page 111 of reference 47.

Tide Recorders

Continuous tide gage recorders have been installed at many locations to obtain information concerning tidal conditions in the San Francisco Bay system and the Delta. Some tide gages in the Delta and bays have been in operation for many years. Others were installed for shorter periods of time to obtain water level information for specific purposes. The location of continuous tide gage recorders operating during 1959 are shown on Plate 3, "Tide Gage Locations, San Francisco Bay System", and Plate 4, "Tide Gage Locations, Sacramento-San Joaquin Delta". Also shown on these plates is a centerline of the mean movement of tidal flow, and locations at which tidal measurements have been made for specific purposes referred to in the text. The accumulated mileage from the Golden Gate is indicated along the centerline. Table 1 lists the number and location of the recorders shown on Plate 3 and 4, the agency which operates the recorder, the height of mean sea level datum above the gage zero elevation (where known), and if the recorder was a temporary or permanent installation during 1959.

The datum to which the tide gage recorder staff is referenced is U. S. Coast and Geodetic Survey (USC&GS) sea level datum of 1929. It should be pointed out that because of surface subsidence in the Delta area, bench marks used to establish tide gage elevations may be inaccurate.

Water Surface Elevations

Tidal stages within the San Francisco Bay system and Delta were determined from records of water surface elevations measured at several tide gage recorder locations. These water surface elevations are plotted on Plate 5, "Mean Water Surface Elevations, North San Francisco Bay", and on Plate 6, "Mean Water Surface Elevations, Sacramento-San Joaquin Delta". The water surface elevations shown are for the four peak tidal phases, mean higher high water, mean high water, mean low water, and mean lower low water. The surface elevation at mean half tide is also shown on Plate 5 and 6. These are averages of the four peak water surface elevations recorded at the tide gage locations for a two-month period in 1953, and are representative of mean half tide water surface elevations for other periods.

Tidal Prism

As used in this text, the tidal prism at a location is the difference in volumes of water from points within the Delta to the point at which the forced wave is no longer measurable. This volume is a constantly varying one, dependent upon the instantaneous water surface elevation, which in turn is dependent upon the tidal phase and stream flow. An amplification of "tidal prism" may be found in reference 8. To determine the tidal prism, use is made of the water surface elevations obtained from the tide recorders. Plate 7, "tidal prism", shows the relationship of tidal prism to tidal range for three locations within the Bay system. These locations are at (1) the Presidio, (2) Dillon Point, and (3) Chipps Island. Tidal range is defined as the difference in water surface elevations between successive tidal phases.

Because of the changing water surface elevations in the Delta channels, water is stored in the channels during rising water elevations and released from storage during descending water elevations. The quantity of water passing a given location between successive tidal phases can be determined if the tidal prism and the inflow to the tidal estuary above that location are known.

Flow Conditions in Delta Channels

Flow conditions in Delta channels are influenced by both tide and stream flow. Stream flow entering the Delta plays a major role in the net movements of water in the complex of interconnected channels. The operations of the Central Valley Project in transferring surplus waters from the Sacramento River basin across the Delta complicate the hydraulic flow picture. Export of surplus waters at the Tracy Pumping Plant in the southern portion of the Delta causes a reversal of net movement of water in certain channels.

Relationships of flow in the more important cross-Delta transfer channels to flows in other main channels have been developed, and the distribution of flows between some of the parallel waterways has been determined from flow measurements conducted on these channels. Because of tidal activity, flows in the channels throughout the Delta will reverse in direction or pulsate. Because of the stream flow in channels where currents reverse direction, the predominant flow is toward the ocean on the ebb tide. In other words, the volume of water moving seaward is larger than the volume of water moving inland during the flood tide. At most locations in the Delta where reversal of current takes place, the current generally leads the tide wave, so that the peak flows occur prior to the peak water surface elevations. During periods of low river flow, during the summer months, the point of nonreversal of current in the Sacramento River is in the vicinity of Clarksburg. Upstream from this location the flow is always downstream, but at higher velocities during the ebb tides than during the flood tides.

In the upstream channels stream flow plays a major role in determining the flows through those channels. In the downstream channels of the Delta tide is the predominant factor in determining the flow. An example of the first case is Georgiana Slough, where flow in the slough depends primarily on flow in the Sacramento River. An example of the latter case is Threemile Slough, which connects the Sacramento and San Joaquin Rivers. The flow in Threemile Slough is affected but slightly by stream flow in the rivers, but is greatly influenced by tidal conditions.

To determine the distribution of flows in the many waterways of the Delta, use was made of tidal flow measurements conducted in the Delta over a number of years. Tidal flow measurements, sometimes called tidal cycle measurements, are conducted continuously for a period of a lunar day1/ so that the average flow during the tidal cycle can be determined.

Standard current metering equipment is used in determining these measurements. The measurements are made at a cross section of the channel by metering from a boat attached to a cable (tag line) stretched across the channel. Between 12 and 20 stations along the cross sections are metered each hour at 0.2 and 0.8 of their depths. The flow through each

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1/ A lunar day is the time between successive transits of the moon; 24 hours, 50 minutes, 30 seconds.

station is computed using the mean velocity of the two metered depths. The total flow through the channel cross section for each hour is the summation of flows at all stations in each cross section. The total flow is then plotted against the mean time of the hourly measurements of flow at the cross section.

Plate 8, "Tidal Flow Measurement Locations" shows the locations where tide flow measurements have been made. Tables 2 and 3 summarize information obtained from the measurements. These measurements were graphed in order to determine the net flow for the tidal cycle. The areas of the flow curves between corresponding tidal peaks, about 25 hours apart, are algebraically summed and divided by the time between the peaks.

TABLE 2

TIDAL FLOW MEASUREMENTS
SACRAMENTO RIVER AT SACRAMENTO
(IN SECOND-FEET)

Location No. 1[1]

Date of Measurement	Net Flow	Maximum Flow	Minimum Flow
Dec. 3 & 4, 1947	9,230	9,800	5,810
May 8 & 9, 1950	23,073	23,900	21,600
June 8 & 9, 1950	18,800	20,360	17,275
July 10 & 11, 1950	7,661	7,525	4,090
Sept. 7 & 8, 1950	8,185	10,325	5,075
Oct. 10 & 11, 1950	8,697	10,300	6,270
Nov. 9 & 10, 1950	12,200	13,750	10,290
Apr. 9 & 10, 1951	28,980	30,275	28,360
May 28 & 29, 1951	22,410	24,700	20,100
June 20, 21, 22, 1951	9,341	11,625	5,275
July 24 & 25, 1951	9,430	11,025	7,100
Sept. 6 & 7, 1951	10,800	12,600	8,560
Sept. 12 & 13, 1951	10,305	12,200	8,050
Nov. 8 & 9, 1951	9,590	10,560	7,600
July 7 & 8, 1952	23,215	25,400	21,000
Aug. 12 & 13, 1952	9,465	10,925	6,825
Aug. 13 & 14, 1952	9,614	11,080	7,575
Aug. 13, 14, & 15, 1952	9,716	11,080	7,575
Aug. 14 & 15, 1952	9,983	11,325	7,975
Aug. 15 & 16, 1952	9,936	11,325	7,690
Aug. 15, 16, & 17, 1952	9,926	11,220	7,065
Aug. 16, 17, & 18, 1952	9,796	11,100	7,065
Aug. 17 & 18, 1952	10,023	11,380	7,890
Aug. 17, 18, & 19, 1952	10,017	11,380	7,860
Aug. 18, 19, & 20, 1952	9,975	11,400	7,850
Aug. 19 & 20, 1952	9,939	11,400	7,480
Aug. 19, 20, & 21, 1952	9,965	11,075	7,480
Aug. 20, 21, & 22, 1952	10,110	11,450	8,060
Aug. 21 & 22, 1952	10,165	11,450	8,450
Aug. 21, 22, & 23, 1952	10,100	11,290	8,380
Aug. 22, 23, & 24, 1952	9,961	11,090	7,970
Aug. 23 & 24, 1952	9,962	11,050	7,970
Aug. 23, 24, & 25, 1952	9,908	11,090	7,840
Aug. 24 & 25, 1952	10,008	11,095	7,840
Aug. 25 & 26, 1952	10,097	11,500	7,920

TABLE 2 (Continued)

TIDAL FLOW MEASUREMENTS
SACRAMENTO RIVER AT SACRAMENTO
(IN SECOND-FEET)

Location No. 1[1/]

Date of Measurement	Net Flow	Maximum Flow	Minimum Flow
Aug. 25 & 26, 1952	10,097	11,500	7,920
Aug. 25, 26, & 27, 1952	10,027	11,500	7,420
Aug. 26 & 27, 1952	9,978	11,250	7,390
Aug. 26, 27, & 28, 1952	9,763	11,250	7,175
Sept. 18 & 19, 1952	12,610	13,560	11,200
Oct. 4 & 5, 1952	10,460	11,800	8,600
Oct. 27 & 28, 1952	9,553	10,500	8,000
Nov. 12 & 13, 1952	9,340	10,760	7,150
Nov. 19 & 20, 1952	11,965	13,380	9,775
Mar. 26 & 27, 1953	32,645	33,420	32,020
Apr. 23 & 24, 1953	28,620	31,350	25,300
May 12 & 13, 1953	28,380	29,350	27,300
July 1 & 2, 1953	16,365	17,275	15,425
July 17 & 18, 1953	8,825	10,440	6,475
July 24 & 25, 1953	8,100	10,100	4,810
Aug. 17 & 18, 1953	8,450	9,970	6,060
Oct. 6 & 7, 1953	10,160	11,140	8,725
Oct. 22 & 23, 1953	11,095	12,325	9,460
Nov. 30, & Dec. 1, 1953	16,565	17,515	15,450
June 24 & 25, 1954	8,307	9,850	5,300
July 27 & 28, 1954	7,920	9,800	5,100
Aug. 16 & 17, 1954	8,968	10,410	6,850
Sept. 16 & 17, 1954	11,150	12,700	8,525
Nov. 9 & 10, 1954	9,694	10,960	6,880
Mar. 8 & 9, 1955	11,975	13,060	10,430
June 20 & 21, 1955	9,292	12,000	6,175
July 26 & 27, 1955	9,474	11,350	6,700
Aug. 15 & 16, 1955	9,268	10,850	6,260
Sept. 22 & 23, 1955	10,045	11,120	7,900
Oct. 17 & 18, 1955	8,289	10,075	5,240
Nov. 17 & 18, 1955	9,875	11,325	7,330
July 10 & 11, 1956	11,985	13,725	9,450
Sept. 12 & 13, 1956	13,590	14,600	12,100
Nov. 28 & 29, 1956	12,285	13,450	9,950

TABLE 2 (Continued)

TIDAL FLOW MEASUREMENTS
SACRAMENTO RIVER AT SACRAMENTO
(IN SECOND-FEET)

Location No. 1[1]

Date of Measurement	Net Flow	Maximum Flow	Minimum Flow
Jan. 30 & 31, 1957	10,037	11,125	7,600
Apr. 22 & 23, 1957	24,510	25,875	23,800
June 27 & 28, 1957	9,261	11,650	5,900
Aug. 27 & 28, 1957	9,630	11,325	7,425
Oct. 28 & 29, 1957	18,370	19,300	17,600
Dec. 10 & 11, 1957	13,615	14,775	11,975
July 16 & 17, 1958	13,755	15,525	11,500
Oct. 21 & 22, 1958	12,960	14,520	11,475
Dec. 8 & 9, 1958	13,225	15,140	10,900
Apr. 23 & 24, 1959	8,000	10,600	4,050
Sept. 30, & Oct. 1, 1959	9,525	11,300	6,700
Oct. 20 & 21, 1959	7,705	9,450	4,875
Nov. 24 & 25, 1959	6,915	8,200	4,460
Jan. 14 & 15, 1960	10,875	12,350	8,700

1/ All tidal flow measurements at Sacramento made by DWR.

TABLE 3

TIDAL FLOW MEASUREMENTS, SACRAMENTO-SAN JOAQUIN DELTA

Location number 1/	Channel and location of measurement	Date and agency 2/ conducting measurement	Tidal flow measurement, second-feet			Mean flows during period of measurement, second-feet			Direction flow 4/, 5/
			Net flow	Maximum flow	Minimum flow	Sacramento River at Sacramento	San Joaquin River at Vernalis	Delta-Mendota Canal	
2	Sacramento River at Courtland	Sept. 6-7, 1951 - USBR	10,530	18,200	-2,500 3/	10,800	966	--	A
		Sept. 12-13, 1951 - DWR	9,020	18,200	-3,440	10,350	940	--	A
3	Sacramento River below head of Georgiana Slough	May 28-29, 1951 - USBR	9,130	13,250	1,700	22,600	11,475	--	A
		June 20-21, 1951 - USBR	4,800	11,150	-7,025	10,450	3,580	--	A
		June 21-22, 1949 - DWR	2,740	9,050	-7,010	7,295	1,180	--	A
4	Sacramento River near Ryde	July 24-25, 1951 - USBR	3,760	10,450	-7,150	9,500	615	--	A
		Sept. 6-7, 1951 - DWR	2,315	19,900	-8,800	10,850	966	--	A
		Sept. 24-25, 1952 - USBR	3,365	11,450	-7,400	11,650	1,625	--	A
		July 1-2, 1953 - DWR	5,005	12,700	-6,800	16,500	3,700	2,808	A
		July 24-25, 1953 - DWR	1,726	11,500	-10,300	8,120	650	2,989	A
5	Sacramento River below Ryde	Sept. 12-13, 1951 - USBR	2,030	11,400	-10,300	10,700	925	--	A
		July 17-18, 1953 - DWR	2,000	9,700	-8,950	8,930	797	2,812	A
6	Sacramento River near Mayberry Slough	Sept. 14-17, 1953 - DWR	--	105,000	-72,000	11,520	523	511	A
7	Sutter Slough above Elkhorn Slough	June 21-22, 1949 - DWR	1,525	3,650	-1,600	7,295	1,180	--	A
8	Sutter Slough near head	Sept. 6-7, 1951 - USBR	2,150	4,300	-2,025	10,850	966	--	A
		April 8-9, 1952 - USBR	17,330	18,375	16,250	69,400	20,350	--	A
		July 24-25, 1953 - DWR	1,351	4,575	-2,875	8,120	650	2,989	A
		Sept. 12-13, 1951 - DWR	1,820	4,650	-2,425	10,700	925	--	A
9	Steamboat Slough near head	June 21-22, 1949 - DWR	1,040	3,325	-2,475	7,295	1,180	--	A
		Sept. 6-7, 1951 - USBR	1,330	4,200	-2,850	10,850	966	--	A
		Sept. 12-13, 1951 - DWR	1,160	4,350	-3,500	10,700	925	--	A
		July 24-25, 1953 - DWR	650	4,350	-3,880	8,120	650	2,989	A
10	Steamboat Slough at .9 mile below head	April 8-9, 1952 - USBR	15,000	16,085	14,180	69,400	20,350	--	A
11	Delta Cross Channel near head	Sept. 6-7, 1951 - DWR	3,285	8,325	-1,225	10,850	966	--	B
		Sept. 12-13, 1951 - USBR	3,500	9,400	-1,900	1,070	925	--	B
		Oct. 30-31, 1951 - USBR	3,640	9,100	-550	11,200	1,685	--	B
		Sept. 24-25, 1952 - USBR	3,234	8,500	-1,100	11,650	1,625	--	B
		July 1-2, 1953 - DWR	3,830	9,700	-200	16,500	3,700	2,808	B
		July 17-18, 1953 - DWR	2,911	7,850	-1,400	8,930	797	2,812	B
		July 29-30, 1954 - DWR	2,961	7,930	-1,700	7,975	321	3,298	B
		June 14-15, 1955 - DWR	3,236	8,190	-1,090	11,400	1,590	3,327	B
		April 29-30, 1957 - DWR	4,225	9,800	-550	16,050	1,685	1,868	B
12	Georgiana Slough near head	May 28-29, 1951 - USBR	3,150	4,940	2,100	22,550	11,350	--	C
		June 20-21, 1951 - USBR	2,150	3,775	-160	10,450	3,580	--	C
		July 24-25, 1951 - USBR	2,250	4,180	950	9,510	615	--	C
		Sept. 12-13, 1951 - USBR	1,968	3,325	790	10,700	890	--	C
		April 10-11, 1952 - USBR	9,920	10,280	9,620	6,770	21,200	--	C
		Sept. 24-25, 1952 - USBR	2,055	3,080	635	11,650	1,625	--	C
		July 1-2, 1953 - DWR	2,582	3,730	1,550	16,500	3,700	2,808	C
		July 17-18, 1953 - DWR	1,775	2,750	750	8,930	797	2,812	C
		July 24-25, 1953 - DWR	1,820	3,110	190	8,120	650	2,989	C
		July 29-30, 1954 - DWR	1,767	3,000	0	7,975	321	3,298	C
13	Georgiana Slough near mouth	Sept. 6-7, 1951 - DWR	1,820	2,810	710	10,850	966	--	C
14	Georgiana Slough at Walnut Grove	June 14-15, 1955 - DWR	2,083	2,860	1,150	11,400	1,590	3,347	C
		April 29-30, 1957 - DWR	2,600	3,660	1,480	16,050	1,685	1,868	C
15	Mokelumne River at Galt Road Bridge	August 29-30, 1950 - DWR	16	118	-88	7,055	624	--	B
		Oct. 2-3, 1950 - DWR	97	160	--	8,135	1,050	--	R
16	South Fork of the Mokelumne River below New Hope Landing	Oct. 30-31, 1951 - USBR	730	1,510	-900	11,200	1,685	--	C

TABLE 3

TIDAL FLOW MEASUREMENTS, SACRAMENTO-SAN JOAQUIN DELTA (continued)

Location: number 1/	Channel and location of measurement	Date and agency 2/ conducting measurement	Tidal flow measurement, second-feet:			Mean flows during period of measurement, second-feet:			Direction (+) flow 4/, 5/
			Net flow	Maximum flow	Minimum flow	Sacramento River at Sacramento	San Joaquin River at Vernalis	Delta-Mendota Canal	
17	North Fork of the Mokelumne River below Millers Ferry Swing Bridge	Oct. 30-31, 1951 - USBR	3,500	4,325	2,410	11,200	1,685	--	C
18	Stone Lake drain near Lambert Road	March 22-23, 1956 - DWR	39	117	-9	41,650	4,435	468	D
		April 16-17, 1956 - DWR	--	110	-53	32,800	7,545	871	D
		May 17-18, 1956 - DWR	22	109	-10	36,900	9,045	290	D
		June 25-26, 1956 - DWR	-15	106	-138	16,700	7,790	2,528	D
		July 18-19, 1956 - DWR	-38	80	-166	12,400	1,935	3,202	D
		Aug. 22-23, 1956 - DWR	-13	55	-97	11,700	1,645	2,741	D
		Oct. 4-5, 1956 - DWR	-15	78	-130	7,885	637	1,720	D
19	False River below Piper Slough	Aug. 28-29, 1952 - USBR	585	36,250	-35,000	9,665	1,280	--	E
		July 15-16, 1953 - DWR	-250	36,750	-39,500	9,620	938	2,775	E
20	Fishermans Cut at 1/2 mile north of False River	Aug. 28-29, 1952 - USBR	-443	2,925	-3,450	9,665	1,280	--	E
21	False River near Fishermans Cut	July 15-16, 1953 - DWR	70	3,700	-4,400	9,620	938	2,775	E
22	False River at 1,000 feet east of Webb pump	Aug. 20-21, 1953 - DWR	--	16,000	-15,650	8,940	637	2,291	E
23	False River near head	Sept. 22-23, 1953 - DWR	37	6,000	-6,350	9,055	781	156	E
24	Dutch Slough at Jersey Island bridge	Aug. 28-29, 1952 - USBR	-193	6,400	-6,450	9,665	1,280	--	E
		July 15-16, 1953 - DWR	100	6,225	-6,775	9,620	938	2,775	E
25	Dutch Slough at Burroughs Ranch	Aug. 18-19, 1955 - DWR	-10	7,100	-7,600	9,145	449	2,936	E
26	Sand Mound Slough near Old River	Sept. 10-11, 1953 - USBR	410	7,200	-7,225	10,550	898	754	E
27	Old River above Rock Slough	Sept. 18-19, 1952 - USBR	116	11,100	-12,000	12,600	1,925	--	E
		April 14-15, 1953 - DWR	-647	10,550	-12,950	20,000	929	1,526	E
		July 9-10, 1953 - DWR	-256	12,800	-13,100	11,900	2,340	2,686	E
		Aug. 12-13, 1953 - DWR	-1,075	9,550	-11,500	10,500	665	2,387	E
		Sept. 3-4, 1953 - DWR	-728	11,250	-11,975	11,700	901	1,334	E
28	Old River at one mile above highway bridge	July 30-31, 1951 - USBR	-750	8,400	-11,200	9,775	1,022	--	E
29	Old River at Clifton Court Ferry	Aug. 28-29, 1951 - DWR	--	7,200	-9,300	10,200	996	--	E
		July 22-23, 1954 - DWR	-3,200	4,375	-12,125	7,695	358	3,294	E
		July 25-26, 1955 - DWR	-2,523	5,375	-10,400	8,580	384	2,607	E
		Feb. 9-10, 1957 - DWR	-2,712	5,550	-9,800	9,955	1,760	4,285	E
30	San Joaquin River near navigation light No. 36	Sept. 11-12, 1950 - DWR	20	7,800	-9,700	10,150	825	--	E
		Aug. 28-29, 1951 - DWR	92	10,225	-10,800	10,200	996	--	E
31	San Joaquin River at Antioch Bridge	Sept. 14-17, 1953 - DWR	--	152,000	-124,000	11,520	523	511	E
32	San Joaquin River near Brandt Bridge	Aug. 1-2, 1951 - USBR	32	2,080	-2,100	10,200	476	--	E
	San Joaquin River at Brandt Bridge	Aug. 28-29, 1951 - DWR	210	1,900	-1,745	10,200	996	--	E
		Aug. 26-27, 1954 - DWR	-220	1,700	-2,300	7,790	645	2,821	E
		July 26-27, 1955 - DWR	-97	1,480	-2,000	8,530	360	3,354	E
		Feb. 9-10, 1957 - DWR	325	1,870	-1,610	9,950	1,760	4,285	E

TABLE 3

TIDAL FLOW MEASUREMENTS, SACRAMENTO-SAN JOAQUIN DELTA (continued)

Location number [1]	Channel and location of measurement	Date and agency [2] conducting measurement	Tidal flow measurement, second-feet			Mean flows during period of measurement, second-feet			Direction (+) flow [4], [5]
			Net flow	Maximum flow	Minimum flow	Sacramento River at Sacramento	San Joaquin River at Vernalis	Delta-Mendota Canal	
33	Victoria Canal 2.5 miles from Middle River	July 30-31, 1951 - USBR July 9-10, 1953 - DWR Aug. 12-13, 1953 - DWR	-210 582 803	3,350 4,475 4,100	-3,650 -3,075 -2,450	9,775 11,900 8,790	662 2,340 665	-- 2,686 2,385	F F F
34	Old River below Victoria Canal	Aug. 25-26, 1955 - DWR Feb. 9-10, 1957 - DWR	-1,708 -1,705	4,800 5,300	-7,400 -8,550	8,580 9,950	384 1,760	2,608 4,285	E E
35	Grant Line Canal at mouth	Aug. 28-29, 1951 - DWR	377	3,275	-3,375	10,200	996	--	E
36	Old River at Sallee site	Aug. 28-29, 1951 - DWR	113	1,114	-925	10,200	996	--	E
37	Middle River below head of Salmon Slough	Aug. 9-10, 1955 - DWR	29	107	12	9,615	403	3,217	E
38	Threemile Slough near Sacramento River	Nov. 13-14, 1946 - DWR July 15-16, 1959 - DWR	-20 950	37,000 38,000	-39,000 37,000	8,282 9,295	2,470 269	-- 3,915	G C
39	Threemile Slough near San Joaquin River	Aug. 25-26, 1955 - DWR July 15-16, 1959 - DWR Aug. 25-26, 1959 - DWR	170 1,000 1,750	26,000 32,500 24,600	-27,000 27,000 26,000	8,580 9,295 9,685	384 269 611	2,608 3,915 2,863	C C C
40	Salmon Slough near head	Aug. 9-10, 1955 - DWR	242	1,430	-1,075	9,615	403	3,217	H
41	Middle River below division	Aug. 1-2, 1951 - USBR	380	14,700	-8,900	10,200	476	--	I
42	Middle River at Mowry Bridge	Feb. 9-10, 1957 - DWR	25	101	-9	9,950	1,760	4,285	J
43	Old River above Tracy Pumping Plant intake	July 22-23, 1954 - DWR Feb. 9-10, 1957 - DWR	-146 230	1,900 2,325	-2,115 -1,410	7,695 9,950	358 1,760	3,294 4,285	J J
44	Sherman Island Lake at West break	Sept. 18-19, 1957 - DWR	-100	3,800	-3,600	12,500	1,230	1,730	K
45	Sherman Island Lake at Mayberry Slough	Sept. 18-19, 1957 - DWR	-688	10,100	-14,200	12,500	1,230	1,730	K
46	Sherman Island Lake at Sacramento River levee breaks	Sept. 18-19, 1957 - DWR	779 [3]	29,200 [3]	-32,000 [3]	12,500	1,230	1,730	K

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[1] Refer to Plate 8.

[2] USBR - United States Bureau of Reclamation.
DWR - Department of Water **Resources**.

[3] Flows not actually measured. Values computed.

[4] + Flow from location of measurement to place cited.
- Flow from place cited to location of measurement.

[5] A - Toward Collinsville.
B - Toward New Hope.
C - Toward San Joaquin River.
D - Out of Stone Lake.
E - Toward Antioch.
F - Toward Old River.
G - Toward Sacramento River.
H - Toward Tracy.
I - West.
J - North.
K - Out of Sherman Lake

Distribution of Tidal Flows

Tidal flows entering the Delta from Suisun Bay divide between the Sacramento and San Joaquin River systems. The division of tidal flow was determined from tidal flow measurements conducted simultaneously on the two rivers in September 1953 for a three-day period. The measurements on the Sacramento River were made in the channel about 1,100 feet upstream from Mayberry Slough, and in the San Joaquin River about 500 feet west of the Antioch Bridge. The total volume of water entering and leaving the Delta during the measurement period was determined. Of the total flow entering and leaving the Delta, about 40 percent of the flow was in the Sacramento River and about 60 percent was in the San Joaquin River. The average tidal flow in the Sacramento River was 28,300 acre-feet per tidal phase, and in the San Joaquin River it was 42,300 acre-feet per tidal phase.

Distribution of Net Flows, Sacramento River System

Referring to Plate 4, it can be noted in following the Sacramento River south of Sacramento that there are several branch channels, the Delta Cross Channel, and Sutter, Steamboat, and Georgiana Sloughs, into which flow from the Sacramento River can enter. Sutter Slough, after leaving the Sacramento River, connects with Miner Slough and then continues to join Steamboat Slough. Miner Slough continues westerly and then turns southward to join Cache Slough, which in turn joins the Sacramento River about 3 miles north of Rio Vista. Steamboat Slough also rejoins the Sacramento River at about the same location. Through these channels and the main Sacramento River, flows pass downstream from Sacramento toward Suisun Bay.

Georgiana Slough and the Delta Cross Channel, one natural and the other man-made, provide the means for Sacramento River flow to be diverted into the lower Mokelumne River system. Farther southward Threemile Slough provides a connecting channel to the San Joaquin River. Near the confluence of the two rivers, the levee breaks on lower Sherman Island provide another point of interchange of the waters of the Sacramento and San Joaquin Rivers.

Sutter and Steamboat Sloughs. Tidal flow measurements have been made on these two sloughs simultaneously with tidal flow measurements on the Sacramento River, Georgiana Slough, and the Delta Cross Channel. Two of the three simultaneous measurements were made when the gates on the Delta Cross Channel were opened just prior to metering of flows. Unfortunately, hydraulic conditions in these two instances did not appear to be completely stabilized. Nevertheless, flows in these channels were related to flows in the Sacramento River at Sacramento. This relationship is shown on Plate 9, "Relationships Between Flows in Steamboat Slough, Sutter Slough, and Sacramento River". The division of flow in Sutter and Steamboat Sloughs, as determined in Bulletin No. 27 (Ref. 8), is no longer applicable because of the construction and operation of the Delta Cross Channel to divert Sacramento River flow into the Mokelumne River.

Georgiana Slough and Delta Cross Channel. Flow from the Sacramento River entering Georgiana Slough and the Delta Cross Channel has been related to the flow of the Sacramento River at Sacramento from simultaneous tidal flow measurements conducted on the three channels. The relationships are presented graphically on Plate 10, "Relationships

Between Flows in Georgiana Slough, Delta Cross Channel, and the Sacramento River", which shows flow in the Sacramento River along the horizontal axis and the flow in Georgiana Slough and the Delta Cross Channel along the vertical axis.

On Plate 10 certain points are shown by dashed circles. In determining the normal flow distribution, these points represent data of questionable validity. On two occasions when the flow in the Sacramento River was about 10,800 second-feet, the gates in the Delta Cross Channel headworks were opened about three hours prior to initiation of the flow measurements. This period of time was not sufficient to achieve stable flow conditions, and the flow in the Delta Cross Channel was therefore disproportionately large while the flow in Georgiana Slough was correspondingly smaller. Another measurement made on the Delta Cross Channel, when the flow in the Sacramento River was about 11,200 second-feet, is also of questionable validity since the flow in the cross channel was inconsistent with other measurements.

The flow data presented reveal straight-line relationships between the flow in the Sacramento River, Georgiana Slough, and the Delta Cross Channel. It should be noted that the measurements were made for rates of inflow into the Sacramento River between approximately 8,000 second-feet and 16,000 second-feet. The flow through these channels provides a major portion of the water supply for export from the Delta by the Bureau of Reclamation (USBR).

North and South Forks of the Mokelumne River. The flow from the Sacramento River that passes into the cross channel must later divide between the North and South Forks of the Mokelumne River. Three sets of simultaneous tidal flow measurements have been made on the North and South Forks of the Mokelumne River to determine the flow division between them. The first set of measurements was made on October 30-31, 1951, with a combined flow in the two forks of 4,230 second-feet, 3,640 second-feet of which came through the Delta Cross Channel. Eighty-three percent of the total flow was carried in the North Fork, and seventeen percent was carried in the South Fork. The second set of measurements was made on September 11-12, 1956, with a combined flow of 3,625 second-feet in the two forks, 3,520 second-feet of which arrived from the Delta Cross Channel. In this measurement, 80 percent of the total flow was carried in the North Fork and 20 percent in the South Fork.

The third simultaneous measurement was conducted on June 28-29, 1956, but on this occasion the Delta Cross Channel gates were closed and the combined flow in the two forks was only 1,618 second-feet. At this time 54 percent of the combined flow was carried in the North Fork and 46 percent in the South Fork of the Mokelumne River. The difference in flow division between this measurement and the other two measurements can be understood by realizing that when the cross channel gates are closed the flow from the Mokelumne River can divide easily between the North and South Forks. When the cross channel gates are open, and flow in the cross channel is large in comparison to flow in the Mokelumne River, the channels leading to the North Fork are about one and one-half times as large as the channels leading to the South Fork. Because of this, more of the cross channel flow reaches the North Fork of the Mokelumne River than the South Fork.

Threemile Slough. Threemile Slough connects the Sacramento and San Joaquin Rivers about 3 miles south of the City of Rio Vista, and is another transfer point of water from the Sacramento River to the San Joaquin River. Four tidal flow measurements have been made in the slough under what may be termed present Delta channel conditions--November 1946, August 1955, July 1959, and August 1959. These measurements indicate an average tidal flow through Threemile Slough of 10,500 acre-feet per tidal phase for a mean range of tide. The peak flow is about 30,000 second-feet between the two rivers, but the net flows are less than 2,000 second-feet. Table 3 lists the dates of these tidal flow measurements, the net flow through Threemile Slough, and the direction of flow.

Sacramento River inflow to the Delta was about 8,500 second-feet during the 1946 and 1955 measurements, and about 9,500 second-feet during the 1959 measurements. The large variation in net flow through the Threemile Slough under present channel conditions is similar to the large variation in net flow through the slough observed in 1929. The flow through Threemile Slough, as determined in 1929, was noted in Bulletin No. 27. From the limited measurements of flow in Threemile Slough under present channel conditions, it is concluded that the flow through the slough is primarily dependent upon the character of the tides, and is not related to the flow in the Sacramento River. This is the same conclusion reached by the writers of Bulletin No. 27. The tidal flow through Threemile Slough is toward the San Joaquin River on the flooding or rising tide in the Delta, and thus contributes to the tidal flow moving into the San Joaquin River system. The mean flow of approximately 10,500 acre-feet per phase in Threemile Slough is about one-fourth of the mean tidal flow of approximately 42,300 acre-feet per phase in the San Joaquin River near the Antioch Bridge, or one-fifth the total of the two. The sum of the San Joaquin River tidal flow, as measured near the Antioch Bridge, and the Threemile Slough tidal flow makes up the total tidal flow into the San Joaquin River system.

Confluence of the Sacramento and San Joaquin Rivers. There are two locations in the vicinity of the confluence of the Sacramento and San Joaquin Rivers at which waters in the two rivers can interchange. One, of course, is the point of confluence of the rivers, and the other is upstream from the confluence in the submerged lower portion of Sherman Island in the area west of Mayberry Slough, referred to as Sherman Lake. In the submerged portion of Sherman Island, flooding tidal water from the Sacramento River enters the lake through the levee breaks on the northern side of Sherman Island. Water from the San Joaquin River enters the lake through a levee break at the western part of Sherman Island. Water exits from the lake through Mayberry Slough and enters the San Joaquin River by two channels about 2 miles upstream from Antioch.

In September 1957, tidal flow measurements determined the average net flow in Mayberry Slough to be about 700 second-feet in the direction from the Sacramento River to the San Joaquin River. The net flow from the Sacramento River to the San Joaquin River through Mayberry Slough appears to be caused by the difference in tidal regimen conditions on the two rivers on opposite sides of Sherman Island and the hydraulic characteristics of channels through the submerged portion of Sherman Island. During flood tides, the depth of water is relatively great and the frictional resistance to flows from the Sacramento River to the

San Joaquin River is nominal. On ebb tides, when the depth of water is less, there is greater resistance to flow in the direction from the San Joaquin River toward the Sacramento River. Therefore greater quantities of water flow from the Sacramento River to the San Joaquin River on flood tides than the quantities which flow in the opposite direction on ebb tides.

Distribution of Flow in San Joaquin River System

Simultaneous tidal flow measurements in channels in the San Joaquin River system have not been very numerous. As a result the distribution of flow among channels in the San Joaquin River system has not been determined. The only relationship of flow determined was between flow in the Delta-Mendota Canal, the San Joaquin River near Mossdale, and the San Joaquin River at Brandt Bridge.

Water entering the Delta via the San Joaquin River at Vernalis at times when the Delta-Mendota Canal pumps are not operating, flows down the river to the head of Old River. At this location the flow divides between Old River and the San Joaquin River, with about 57 percent of the flow entering Old River and about 43 percent of the flow remaining in the San Joaquin River. This division of flow was determined by the Sacramento District Corps of Engineers.

With the operation of the Delta-Mendota Canal pumping plant, the demand at the pumps places a demand on the flow in Old River. The demand at the pumps during times of low flow in the San Joaquin River increases the flow of water down Old River over that which would normally flow in that channel. This in turn decreases flow in the San Joaquin River downstream from Old River. When flow entering the San Joaquin

River at Vernalis is insufficient to meet pumping demand at the Delta-Mendota Canal, water in the San Joaquin River downstream from Old River will flow upstream or southerly in the San Joaquin River.

Since the installation of the Tracy pumps in 1950, there have been six tidal flow measurements conducted simultaneously on Old River and the San Joaquin River at times of different pumping rates into the Delta-Mendota Canal. From data obtained by these measurements, the ratio of the flow in the Delta-Mendota Canal to the flow in the San Joaquin River at Mossdale was plotted against the ratio of flow in the San Joaquin River at Brandt Bridge to the flow in the San Joaquin River at Mossdale. This relationship is shown on Plate 11, "Ratio of Flow at Two Locations on San Joaquin River as Influenced by Delta-Mendota Canal Pumping". Flow into Old River is then the algebraic difference of the flow in the San Joaquin River at Mossdale and flow in the San Joaquin River at Brandt Bridge.

CHAPTER III. SALINITY INCURSION

In this report, salinity incursion is defined as the invasion of sea water into tidal estuaries or channels by tidal action. Its meaning differs from sea water or salinity intrusion in that the latter defines the invasion of sea water into ground water aquifers. It is recognized that in past reports of the department and its predecessor agencies, salinity intrusion referred to invasion of sea water into tidal channels, but hereinafter the term salinity incursion is used.

The amount of salinity is expressed as the concentration of the chloride ion (Cl) in parts per million parts water (ppm) by weight. Salinity is also expressed in parts total dissolved solids (TDS) per million parts water, but in this text, salinity as parts chloride per million parts water is implied unless otherwise noted.

To provide a background of salinity conditions in the Sacramento-San Joaquin Delta, historical salinity conditions in the Delta were examined as well as present conditions and the problems associated therewith. The basic factors affecting salinity incursion were also covered. Records defining salinity conditions and patterns in the Delta, and data obtained from special field measurements to identify specific salinity conditions are presented, as well as methods used to measure salinity concentrations.

The relationship of salinity incursion to Delta outflow, and the rate of Delta outflow for control of salinity in the Delta, are the other topics discussed in this chapter.

Salinity Conditions in Sacramento-San Joaquin Delta

Salinity incursion into a tidal estuary is a natural phenomenon, so it is not unique to the Sacramento-San Joaquin Delta. Tides in the Pacific Ocean outside the Golden Gate move tremendous volumes of water into and out of the San Francisco Bay and Delta system, mixing the saline ocean water with the fresh fluvial discharges of the Sacramento and San Joaquin Rivers. At times when the river discharges are small the saline ocean water invades the estuarine channels and remains until flushed out by increased stream flow.

Historical Salinity Conditions

The presence of saline water in upper Suisun Bay and the lower Sacramento-San Joaquin Delta channels was reported by expeditions exploring those waters as early as 1775 and 1841. It was also experienced by settlers along the lower San Joaquin River and in the Suisun marshlands in the late 1880's. Beginning in 1878, Bell Shaw Company provided water for the City of Antioch and pumped water from the river only on low tide during the late summer months of every year. The quality of water at high tide was too brackish for use. Some of the residents stored water in cisterns during the spring for use in the late summer and fall. On several occasions an old-time resident on Twitchell Island, during the years from 1870-1874, found that water 1-1/2 miles up Threemile Slough from its mouth on the San Joaquin River was too brackish for domestic purposes in August and September. Many times drinking water had to be secured from Sevenmile Slough near the Mokelumne River.

The travel record of barges used for bringing water to the California Hawaii Sugar Refining Company plant at Crockett also provides information on the early history of salinity incursion in Suisun Bay and the Delta region. The sugar refining company required water with a salinity of less than 50 ppm, and the record of their barge travel beginning in 1908 gives an accurate account of the location of water of that quality. These records indicate that on many occasions the barges traveled above Threemile Slough on both rivers to obtain good quality water. In 1920, the company abandoned its barges for hauling water during the late summer and fall months of each year, and obtained water from across San Pablo Bay in Marin County. This fact emphatically indicates that sea water incursion had then reached too far upstream to make barge travel economical for transporting the required quality of water.

The seriousness of salinity incursion, however, was not widely recognized until 1917 and in subsequent years, when due to low runoff and increasing upstream water use, sea water penetrated farther into the Delta channels and for longer periods than were formerly observed. The severity of the problem became progressively worse as upstream water uses increased and several extremely dry years were experienced. These effects are generally illustrated on Plate 12, "Historical Salinity Incursion, Sacramento-San Joaquin Delta".

Additional information on historical salinity conditions in the Sacramento-San Joaquin Delta was obtained from Mr. C. W. Schedler, consulting engineer. The department contracted with him for a report on historical salinity conditions in the Delta, and for advice on minimum quality standards for water used by industries located in the western portion of the Delta. A report entitled, "Salt Water Intrusion of Suisun Bay and the Lower Delta", was submitted to the department in September 1957. This report pointed out that under natural conditions Carquinez Strait marked the approximate boundary between fresh and saline waters, and that irrigation and reclamation in the Central Valley were responsible for the gradual decrease in good quality water in the Delta.

It should be noted, however, that from the time of earliest record there has been evidence of salinity incursion into Delta channels. This has occurred during the late summer and fall months in dry years when stream flow in the Sacramento and San Joaquin Rivers was low.

To better understand the phenomenon of salinity incursion and to find a remedy or method of controlling it, intensive engineering studies of salinity problems in the Delta were undertaken during the late 1920's by federal, state, and local agencies. Several reports on these studies were written, and considerable data collected on salinity conditions in the Delta. One of the significant findings of these early studies was that salinity incursion could feasibly be controlled by sufficient outflow from the Delta; a hydraulic barrier. At that time a hydraulic barrier was recommended as the method of salinity control in preference to a physical barrier below the confluence of the two rivers. Therefore, good quality water throughout the Delta could be obtained by storage of winter surplus waters in upstream reservoirs and the release of fresh water during periods when the natural flow was insufficient.

Present Salinity Conditions

Since the construction and operation of the Central Valley Project by the Bureau of Reclamation, there has been a vast improvement in salinity conditions in the Delta during years of low runoff. Water stored in Shasta and Folsom Reservoirs is released during the late summer and fall months for salinity control and other purposes. The effect of these releases in preventing excessive incursion of saline water into Delta channels is dramatically demonstrated on Plate 12. On this plate it is readily seen that the area of the Delta affected by salinity incursion, subsequent to the operation of Shasta Reservoir of the Central Valley Project (CVP), is less extensive than prior to operation of the reservoir. Approximately 7 to 8 percent (33,000 acres) of the Delta acreage is the maximum affected by incursion of the CVP, compared to a maximum of approximately 74 percent (325,000 acres) affected before the CVP.

Another feature of CVP which has contributed to a firmer supply of adequate water for industry located in the western portion of the Delta, is the Contra Costa Canal. Water is diverted into the canal from Rock Slough near Old River. Features were constructed on Sand Mound Slough to physically prevent saline water from directly contaminating the water at the point of diversion. Saline water invading Delta channels must take the long way around through False River and Franks Tract to arrive at the point of diversion to the Contra Costa Canal.

Although present salinity conditions in the Delta are greatly improved over historical conditions from 1920 to 1943, there is still a salinity problem existing in the western portion of the Delta.

When outflow from the Delta is at a minimum during the late summer and fall, saline water is generally present in channels adjacent to Sherman, Jersey, Twitchell, Brannan, and Bradford Islands and Hotchkiss Tract. Under these conditions the water diverted from these channels by siphons, pumps, and through subsurface seepage, is of poor quality and becomes detrimental to the crops. The City of Antioch cannot divert water from the river for municipal purposes, and most industry along the San Joaquin River cannot use the water for process purposes.

The Contra Costa Canal provides the alternative source of water to meet the needs of the Cities of Antioch and Pittsburg, and industries adjacent to the river. Recently, however, the quality of water delivered from the Contra Costa Canal at times of minimum Delta outflow has not met the needs of all users. In 1959, the concentration of chlorides in the canal water reached proportions that made softening of boiler water, at the rate and quantity required, infeasible. In fact one plant had to close down completely for about three weeks. The higher salinity concentration also affected manufacturers of products which require high quality water for processing.

Factors Affecting Salinity Conditions

The two basic factors affecting salinity incursion in the Delta are tidal activity and stream flow. Tidal activity is the activating mechanism which causes the saline ocean water to move through the Golden Gate into San Francisco Bay and thence upstream into Delta channels to mix with the fresh-water flows from the Sacramento, San Joaquin, and smaller tributary rivers. Flows entering the Delta are modified by depletion of water from the channels for consumption by crops, vegetation, evaporation, and diversion out of the Delta for export elsewhere. The remaining stream flow passing into Suisun Bay (Delta outflow) determines the extent and pattern of salinity incursion into the Delta.

In a tidal estuary the pattern of salinity incursion can take one of three forms: (1) a salt-water wedge or highly stratified vertical section, in which the denser sea water moves into the estuary along the bottom of the channel and the fresher waters override the tongue of salt water; (2) a partially mixed vertical section, in which differences in salinities of the upper and lower layers of the estuary are not quite as severe as in the salt-water wedge; and (3) a fully mixed vertical section, in which top and bottom salinities in the estuary are essentially the same throughout the tidal cycle. These have been categorized into salinity patterns in an estuary by the Corps of Engineers. An analysis of available data revealed two significant ratios that appeared to influence the mixing of fresh and saline waters. These ratios were: (1) the ratio of fresh-water discharge to tidal prism; and (2) the ratio of channel width to channel depth.

To assign numerical values to these ratios, the fresh-water discharge was defined as the volume of fresh-water (acre-feet) which flowed into the estuary during an average ebb and flood tidal cycle of 12 hours and 25 minutes. The tidal prism was defined as the volume of water (acre-feet) which entered the estuary from the sea during an average flood tide. The width-depth ratio was derived by dividing the channel width in feet by the mean depth in feet.

If the ratio of fresh-water discharge to the tidal prism was 1 or greater, the estuary was classified as highly stratified. If the ratio was 0.2 to 0.5, the estuary was classified as partly mixed, and a ratio less than 0.1 was classed as well-mixed. A numerical relationship related to mixing characteristics was not found for the width-depth ratio, but the smaller the width to depth ratio, the greater the difference between top and bottom salinities.

In the Delta, salinity data show a partially mixed estuary with slight differences of salinity between top and bottom layers of water. Application of the parameters, above, to the Delta however, indicates a fully mixed estuary. For example: With a mean tidal range of 3.5 feet at Chipps Island (the point at which Delta outflow is measured), and an outflow of about 1,500 second-feet for late summer conditions, the tidal prism from Plate 7 is 88,000 acre-feet and the outflow in 12.5 hours is about 1,550 acre-feet, giving a ratio of approximately 0.017.

In San Francisco Bay and the Delta, the concentration of salinity decreases in the estuary as the distance from the source of salinity increases, creating a flattened S-shaped salinity gradient. The extent of incursion depends upon Delta outflow and fluctuates as the outflow fluctuates. Since Delta outflow varies monthly as well as annually and is a function of stream flow, consumptive use and exportation from the Delta, and salinity conditions in the Delta, the extent of salinity incursion also varies. The rate of outflow affects the duration and extent of incursion, and the shape of the salinity gradient, while the change of the outflow affects the advance or retreat of salinity from the channels.

Technical aspects of salinity incursion, dealing with the differential equations of diffusion and the mechanics of turbulence which generate diffusion, are contained in references 1, 35, 41, 44, 48, 49, and 57.

Records of Salinity Incursion

Considerable data on salinity conditions in the Delta have been collected over the years. Regular salinity sampling, which began in 1924, has continued since then and many special surveys to better define salinity conditions in the Delta have been conducted.

Four-day Salinity Observations

To provide a continual record of salinity observations in the Delta for the purpose of advising farmers and others on the salinity of the river water and to better understand salinity incursion and its control, regular four-day samples of water are collected throughout the Delta and analyzed for salinity determination. Samples are collected by observers at times and locations specified by the department. The samples are taken generally one and one-half hours after high tide and forwarded to the department laboratory for analysis. Sampling locations in the San Francisco Bay System are shown on Plate 13, "Salinity Measuring Locations San Francisco Bay System", and in the Delta on Plate 14, "Salinity Measuring Locations Sacramento-San Joaquin Delta". The location of sampling stations has varied throughout the years, but the locations presently used are sufficient to provide some measure of salinity conditions in the Delta. A tabulation of salinity observations is issued monthly, and the data are published annually in reports entitled, "Report of the Sacramento-San Joaquin Water Supervision". Prior to 1956, the publications in which salinity data were published annually were entitled, "Surface Water Flow for (the Particular Year)".

These data have provided the basic information on salinity conditions in the Delta. Theyshow how salinity varies monthly, seasonally, and annually, and are used to relate salinity to outflow and to make other determinations of salinity incursion patterns in the Delta. A tabulation of regular four-day salinity observations locations is given in Table 4.

U. S. Bureau of Reclamation Salinity Recorders

Another source of data on salinity conditions in the Delta is the records from continuous reading salinity recorders operated by the Bureau of Reclamation. These instruments were installed in connection with the operation of the Contra Costa and Delta-Mendota Canals of the Central Valley Project, and many have been in operation since 1952. The locations of these instruments are also shown on Plates 13 and 14. Some of the instruments are not operated in the winter season because salinity conditions are favorable and their use is not warranted. The locations of these instruments have also changed through the years, as experience has indicated better locations for the most representative salinity measurements. The locations of these instruments are listed in Table 5.

TABLE 4

FOUR-DAY SALINITY SAMPLING LOCATIONS

Number	Location	Number	Location
	San Francisco Bay		San Joaquin River Delta
1	Point Orient	18	Antioch
2	Point Pinole	19	Millers Harbor
3	Point Davis	20	Jersey Island
4	Grand View	21	Threemile Slough
5	Crockett	22	Oulton Point
6	Benicia	23	San Andreas Landing
7	Martinez	24	Opposite Central Landing
8	West Suisun	25	Dutch Slough
9	Innisfail Ferry	26	Webb Ferry
10	Port Chicago	27	East Contra Costa Irrigation District
11	Spoonbill Creek		
12	Pittsburg	28	Clifton Court Ferry
	Sacramento River Delta	29	Mossdale Bridge
13	Collinsville	30	Vernalis (Durham Ferry Bridge)
14	Emmaton (Opposite Toland Landing)		
15	Threemile Slough Bridge		
16	Rio Vista Bridge		
17	Isleton Bridge		

TABLE 5

UNITED STATES BUREAU OF RECLAMATION AND DEPARTMENT OF WATER RESOURCES CONTINUOUS SALINITY RECORDER LOCATIONS

Number	Location	Number	Location
1	Carquinez Strait @ Crockett	10	Delta-Mendota Canal @ head
2	Carquinez Strait @ Martinez	11	Old River @ Holland Tract
3	Sacramento River @ Mallard Slough	12	Middle River @ Highway 4 bridge
4	Sacramento River @ Collinsville	13	San Joaquin River @ Oulton Point
5	San Joaquin River @ Antioch	14	False River @ Webb pump
6	Sacramento River @ Toland Landing	15	San Joaquin River @ San Andreas Landing
7	San Joaquin River @ Jersey Point	16	Sacramento River @ Green's Landing
8	Contra Costa Canal @ Pumping Plant No. 1	17	San Joaquin River @ Vernalis
9	Dutch Slough @ Farrer Park	18	San Joaquin River @ Antioch Bridge 1/

1/ Chloride-ion analyzer owned and operated by the Department of Water Resources.

These salinity recorders were developed by the U. S. Bureau of Reclamation and measure conductivity in micromhos rather than chlorides. The instruments are calibrated and factors determined to relate conductivity to parts total dissolved solids per million parts water. Data from selected instruments are published by the Bureau of Reclamation in monthly operation reports, and the remaining data are filed at the bureau's Tracy field office. These data have been invaluable in shedding additional light on the complicated salinity incursion phenomenon.

Special Salinity Observations

To answer specific questions and obtain more detailed information on salinity conditions in the Delta than could be gleaned from four-day salinity observations and U. S. Bureau of Reclamation salinity recorder records, specific salinity measurement programs were undertaken in the course of the Salinity Control Barrier Investigation. A few of the special measurements were: (1) salinity surveys in and adjacent to lower Sherman Island conducted in 1957; (2) salinity gradient determination along the Sacramento River conducted in 1957; (3) simultaneous salinity-velocity measurements in the upper bays and Delta, conducted in August 1959; (4) slack water salinity gradient observations in the upper bays and Delta conducted in 1959; (5) periodic sampling of channel and drainage water at selected locations throughout the Delta conducted in 1959; and (6) salinity observations in the Montezuma Slough area conducted in 1960. These data added to the reservoir of knowledge on salinity conditions in the Delta and provided a better understanding of the entire problem of salinity incursion. Tabulations and graphical presentation of these data are on file as back-up data for this office report.

Chloride-ion Analyzer

The chloride-ion analyzer is a new device which measures the chloride-ion directly, and records salinity in ppm chlorides continuously on a strip chart. The department has installed such a device in the San Joaquin River at Antioch Bridge. The location is shown on Plate 14, and listed in Table 5. The sensing devices, or probes, are placed at two depths in the channel so that a continuous record of salinity at those depths is available. The instrument has been installed since July 1959, and has proved successful in showing how salinity variation near the bottom of the channel compares to that near the surface.

Relationship of Salinity Incursion to Delta Outflow

All data gathered on salinity conditions in the Delta were analyzed and used in relating salinity incursion to outflow from the Delta. Since one of the prime purposes of salinity incursion studies was to predict the quality of water at any point in the Delta for a given outflow, considerable effort was spent on this task.

Literature reviews were made to see what work in this regard had been conducted, the success of such studies, and if such work was applicable to the problems of the Delta. Letters were sent to many of the leading specialists in tidal hydraulics and salinity incursion asking their assistance in suggesting possible approaches to use in relating outflow from an estuary to salinity incursion therein, or the name of any reports or other information on the subject. Unfortunately these experts could not advise a source of information that contained the ready tools to solve the salinity-outflow relationship in the Delta.

Many approaches were undertaken in attempting to find a relationship of salinity incursion to Delta outflow utilizing available salinity, stream flow, and tidal data. None of these approaches were able to duplicate historical salinity conditions within the Delta to any greater degree of reliability than the relationship derived in Bulletin No. 27 (Ref. 8). Therefore, all conclusions contained in Bulletin No. 76 are based upon the Bulletin No. 27 Salinity-Outflow relationship. Use of this relationship should in no sense preclude the derivation of a more refined analysis of the salinity-outflow problem. Studies now in progress have as their main objective the development of a reliable and accurate solution to the problem.

Bulletin No. 27 Salinity-Outflow Relationship

In this publication a method was developed to relate salinity incursion to fresh-water outflow from the Delta. The relationship derived was the result of a 10-year investigation in which all facets of the salinity problem in the Delta were examined and analyzed. For a complete and detailed understanding of the study, Bulletin No. 27 should be consulted, but for the purposes of this report a summary of the pertinent factors is given.

Tidal Diffusion. In the development of Bulletin No. 27 salinity-outflow relationship, the term tidal diffusion evolved and was used to describe the mechanics by which salinity from the saline bays invaded fresh water in the river channels. Tidal diffusion, defined as the mixing of saline waters from the ocean with fresh waters from the rivers is caused by the effect of tidal currents in the channels of an estuary. Tidal diffusion results in a continuing tendency for saline water to advance upstream. The magnitude of advance or retreat of salinity during a particular time-interval was measured by the volume of water in the channel or channels through which salinity of a particular degree traveled. The total amount of advance or retreat of salinity was due to the combined effect of tidal action and net stream flow in the particular channel section. Tidal diffusion, a function of tidal action, was determined as the difference of the magnitude of advance or retreat of a particular degree of salinity during a particular time interval and the net stream flow into the same channel reaches for the identical time interval. Mathematically, the relationship was expressed as follows:

$$C = D-S$$

Where C equals the amount of advance or retreat of salinity in a particular channel section (expressed as the volume of channel in acre-feet through which salinity of a particular degree advances or retreats during a particular time interval), D equals tidal diffusion, or the effect of tidal action on the total amount of advance or retreat of salinity (expressed in terms of channel volume acre-feet for the same time interval), S equals net stream flow in acre-feet passing the particular channel section during the same time interval, positive if downstream and negative if upstream.

From the equation it is evident that:

1. When the net stream flow "S" is downstream and equal in magnitude to tidal diffusion, "D", the advance of salinity "C" is zero.

2. When the magnitude of tidal diffusion is greater than the net stream flow, salinity incursion results.

3. When, however, the net stream flow exceeds tidal diffusion, retreat of salinity occurs.

When net stream flow in the lower Delta was less than zero or upstream (i.e., Delta consumptive use and diversion from the Delta exceeds inflow), both tidal diffusion and net stream flow become additive, maximizing the advance of salinity. The latter combination of conditions brings about the greatest degree of salinity incursion into the Delta, as has been the case in many of the dry years.

Since the advance of salinity was seldom if every zero for an appreciable length of time during the course of the investigation in the 1920's, tidal diffusion was indirectly determined. For zero advance of salinity, tidal diffusion must be equal and opposite to net stream flow. For known advances of salinity, tidal diffusion was found from the equation by adding the net stream flow when in the downstream direction, or subtracting when in the upstream direction, to volume "S", the volume of water in the channels through which salinity of a particular degree traveled, "C". The net stream flow for any particular section was computed from records of stream flow into the Delta from which estimates of consumptive use above said section were subtracted. Channel volumes were computed from the data of hydrographic surveys of the U. S. Corps of Engineers.

With records of salinity data on stream flow and channel volumes available from 1920 through 1929, values of tidal diffusion in units of acre-feet per day were determined for various degrees of salinity and various locations in the western Delta and Suisun Bay. A series of graphs and charts indicating the relationship of tidal diffusion are shown in Bulletin No. 27. From these relationships of tidal diffusion the relationship of Delta outflow to salinity evolved.

Since tidal diffusion equals net stream flow when the advance of salinity is zero, Delta outflow to control salinity to any desired degree can be shown graphically. The form of the graph used herein is different from that shown in Bulletin No. 27, but the information shown thereon is the same. Such a plot is shown on Plate 15, "Relationship of Delta Outflow to Salinity in Western Delta and Suisun Bay". Outflow from the Delta in second-feet is shown along the abscissa of the graph and salinity in ppm chlorides is shown along the ordinate. Curves on the graph show the relationship of outflow to control salinity for any concentration of salinity for six locations in the western Delta and Suisun Bay. These locations are stations at which regular four-day salinity observations are made and at which long records are available. Thus, for salinity of 1,000 parts chlorides at Antioch, an outflow of about 3,000 second-feet is required. Salinity, of course, is in terms of mean tidal cycle surface zone salinity, which is defined below.

Mean Tidal Cycle Surface Zone Salinity. Mean tidal cycle surface zone salinity is the salinity at a location averaged over a tidal cycle of about 25 hours and measured in the upper foot of the water surface. It is a convenient term to use as a representative of the average salinity of an entire cross section. In Bulletin No. 27, the validity of this relationship was demonstrated. More recent measurements of salinity throughout the Delta have also shown that measurements of salinity in the surface zone are indicative of salinity in an entire cross section.

Since salinity at a location is continually changing due to tidal action, a means of relating salinity observed at any time of the tidal cycle to the mean salinity for the tidal cycle was necessary. Such a relationship was developed from the investigation leading to publication of Bulletin No. 27. Maximum salinity at a location was found to take place at slack water after high tide. It is recalled that on the Pacific Coast there are four tidal peaks each lunar day, of approximately 25 hours. These peaks are termed higher-high, high-low, low-high, and lower-low tide. In the Delta reversal of flow takes place at slack water about one and one-half hours after the tidal peak. Four-day salinity observations in the surface zone are generally made one and one-half hours after higher-high tide so the maximum salinity at a location is observed. From the relationship of observed salinity to mean tidal cycle surface zone salinity, the mean salinity is obtained from the maximum observation.

In Bulletin No. 27, conversion of maximum salinity to mean salinity was in terms of tidal stage. The height of tide was indicated in percent of mean tide for the tidal cycle. Inasmuch as four-day salinity samples were taken after higher-high tide throughout the month, and average monthly salinity at a location was the salinity value used for incursion studies for this report, a means of converting average monthly salinities obtained one and one-half hours after higher-high tide to mean tidal cycle salinity was desired. Salinity records indicated that 80 percent of all salinity observations in the Delta were made one and one-half hours after higher-high tide, most of the others were made one and one-half hours after low-high tide, and a few were made at other times. This occurs because approximately 20 percent of the higher-high tides during the course of a year occur at night. Salinity observation stations are maintained by volunteer personnel and it is more convenient for them to take samples during the day at slack water than at night. During a month, salinity observations are made, generally when tidal heights are 160 percent of the mean tidal height. Therefore, the curve of 160 percent of mean tidal height, shown on Plate LXII of Bulletin No. 27, was used to convert observed salinity observations to mean salinity. Plate 16, "Relationship of Surface Zone Salinity to Mean Surface Zone Salinity", shows this relationship. Mean tidal cycle surface zone salinity is shown along the abscissa and observed salinity taken one and one-half hours after high tide is shown along the ordinate. Salinity on both axes is in terms of ppm chlorides. Future tidal conditions in the Delta are expected to be similar to past conditions, so four-day salinity observations are expected to follow similar patterns. Therefore, the curve relating observed to mean salinity is expected to be representative of future conditions and is used in future estimates of salinity conditions.

<u>Evaluation of Bulletin No. 27 Salinity-Outflow Relationship</u>. To evaluate the reliability of Bulletin No. 27 methods of relating salinity incursion to Delta outflow, a graph was drawn comparing derived salinity at Antioch (determined by Bulletin No. 27 relationship) with historical salinity at Antioch. The comparison was made for the years 1921 through 1955 using historical Delta outflows to obtain derived salinities. The

comparison is shown on Plate 17, "Comparison of Historical Salinity with Derived Salinity at Antioch". The solid line indicates the actual salinities and the dashed line indicates the derived salinities. Historical salinities were obtained from published records of four-day salinity observations made one and one-half hours after higher-high tides. The monthly average of these observations was determined and then converted to mean tidal cycle surface zone salinity by use of the graph on Plate 16. Derived salinities were obtained from the relationship of salinity to outflow for Antioch shown on Plate 15. Monthly outflows were determined from published records of stream flow entering the Delta and precipitation on the Delta modified by estimates of Delta consumptive use, measured diversions to the Delta uplands, and water exportations from the Delta.

On Plate 17, it can be seen that there are many occasions during the summer months when derived salinities indicate sea water (18,000 ppm chlorides). This occurs because at zero outflow, the Delta channels would eventually become saline. It is recognized, however, that for the short periods of time in the past that outflow was zero. it was not sufficient for such a condition to actually develop. The salinity outflow relationship curves, however, does not account for this. Derived salinities also are seen to reach a concentration of 10 ppm chlorides and remain there throughout the winter months when outflows from the Delta are large. Again the derived curves do not accurately represent actual salinity conditions, because at high flows the sea water has been flushed from the channels, and water quality of the inflows and local drainage are the factors influencing the chloride concentrations of the outflow. Another point noted from the plate is that the derived salinities have an earlier occurrence than actual salinities. This is probably due to two factors: (1) the time required for flows to pass through the Delta; and (2) a difference in consumptive use and actual depletion of water from the channels (neither of which is reflected in the salinity-outflow relationship). Even with some of the shortcomings of the salinity-outflow relationship it does give reasonable estimates of salinity incursion. It is presently considered adequate for making future estimates of salinity conditions, particularly when the estimates were to determine the percent of time that salinity of a specific concentration would be available at selected locations.

Other Approaches to Relating Salinity Incursion to Delta Outflow

Although Bulletin No. 27 methods of relating salinity incursion to Delta outflow were used in these studies, other approaches of doing so were attempted. In fact, considerable time and effort were spent in following through unsuccessful approaches. Two of the approaches studied were undertaken by staff personnel, a third analysis was made by Ir. C. Biemond of the Netherlands, and the fourth was undertaken jointly by the department staff and engineers with Charles T. Main Company of Boston, engineering consultants, who studied the feasibility of the State Water Facilities. A short resume of each of these approaches is given to indicate the extent of studies undertaken to find a workable salinity-outflow relationship. Detailed calculations, graphs, and other information gathered and analyzed in these studies are on file as backup data for this appendix.

Tidal Prism Upstream From 1,000 PPM Chloride Location. A somewhat different approach to using the information on tidal diffusion as developed in Bulletin No. 27, was the relation of tidal diffusion to the tidal prism upstream from the location of a particular concentration of salinity. Inasmuch as the location of the maximum incursion of salinity of 1,000 parts chlorides has been determined each year from the four-day salinity analyses, the location of this concentration of salinity was used in this approach. The tidal prism upstream from the mean location of 1,000 ppm chlorides was also easily computed.

Using the data from several selected years in which salinity of 1,000 ppm chlorides extended various distances into the Delta, the tidal prism upstream from the maximum incursion and the outflow from the Delta at the time of maximum incursion was computed. A relationship of Delta outflow to tidal prism volume upstream from the 1,000 ppm chlorides location was then determined by a graphical plot of the data. Combining this plot with the curve showing the relationship of tidal diffusion to tidal prism volume in Bulletin No. 27, gave a composite curve relating Delta outflow to tidal prism upstream from the location of 1,000 ppm chlorides.

It was assumed that closing many of the channels in the Delta and separating them from tidal water by the master levee system as proposed in facilities for the Delta, would decrease the tidal prism in the Delta. With a reduced tidal prism for the Delta it was believed that the curve could be used to determine the outflow necessary to control salinity of 1,000 ppm chlorides at a location near Antioch. But as a result of electronic analog model studies of San Francisco Bay and the Delta conducted at the University of California at Berkeley, it was shown there would be an increased tidal range in the channels not removed from tidal influence. The end result of the removal of channels from tidal influence and the increased tidal amplitudes on the channels remaining under tidal influence, was that no appreciable change in tidal prism in the Delta would take place. Hence, the relationship between Delta outflow and tidal prism volume upstream from the 1,000 ppm chloride location was not applicable in predicting future outflows to control salinity.

Prior to concluding that this approach was not useful for making predictions of salinity conditions under operation of Delta Water Facilities, studies were undertaken to show the validity of the relationship. Field measurements of salinity and stream flow were made on the Napa, Noya, and Russian Rivers to gather sufficient data to make such a determination. Unfortunately the salinity incursion pattern in these rivers was not similar to that in the Delta, so was not adequate to prove the validity of the relationship. Data collected from these studies, and maps showing the locations of measuring points, are included in the backup data of this office report.

Salt-Routing Studies by Machine Computations. This approach to relating salinity incursion to Delta outflow utilized the continuity principle. The estuary was divided into a number of reaches, and the flow into a reach had to equal the flow out of a reach, plus or minus the change of water storage in the reach. In the method, the mixing of fresh and saline waters in a reach was assumed. The amount of mixing, whether complete or partial, was varied, as the method was refined to approach more representative of actual conditions.

The method originally used was programmed for the IBM 650 computer at Stanford University under the direction of Professor Ray K. Linsley, engineering consultant to the Delta water facility studies; by Dr. Robert Oakford, lecturer on industrial engineering; and Donald R. Brisell, a graduate student. Salinity, stream flow diversions, and tidal information in the Delta and Bays gathered during the 17-day lunar cycle measurement of out-flow from the Delta in September 1954, was the basic data used in the salt-routing computations. Results from the IBM 650 computer calculations revealed that the mathematical model as programmed, did not reproduce actual salinity conditions in the Delta.

It was therefore assumed that the phenomena of mixing was not adequately described in the mathematical equations used in the method, and refinements would have to be made. Refinements were made as to the amount of mixing in a reach, and the effect of the salinity gradient on the mixing. Even with these modifications the salt-routing method failed to produce a satisfactory salinity incursion-outflow relationship.

Biemond Analysis. Concurrent with other studies to determine the relationship of sea water incursion into the Delta and the outflow therefrom, the department contracted with Ir. C. Biemond, consulting engineer of the Netherlands, to analyze the problem and submit a report on his findings. Ir. Biemond was the engineer engaged by the department in 1954 to develop comprehensive plans for exporting water across the Delta and providing salinity and flood protection thereon. Ir. Biemond spent several weeks in California and developed the plan known as the Biemond Plan, the principles of which are reflected in the proposed facilities for the Delta.

Ir. Biemond submitted a report to the department divided into three sections. Section 1 described the phenomenon of mixing of fresh and saline waters in Delta channels; Section 2 presented the mathematical analysis of the phenomenon described in Section 1; and Section 3 applied the material covered in Sections 1 and 2 to predict future salinity in the Delta under operation of Delta Water Facilities. The data which Ir. Biemond analyzed for his analysis was the large volume of velocity and salinity information gathered during the 17-day lunar cycle measurement.

Ir. Biemond found from his analysis of data from the lunar cycle measurement that there was a difference in movement of water at two depths of the channel. The difference in water movement, Ir. Biemond believed, was the reason for the difference in salinities at the two depths. He, thus, concluded that dual-layer flow existed in the Delta channels. He made a mathematical evaluation of the dual-layer theory and demonstrated that calculations could be made to predict changes in tidal flow and salinities. He then used the theory developed and information on salinity gradients in the estuary to predict future salinity conditions with Delta facilities in operation.

The method was reviewed by Dr. Einstein, Professor of Hydraulic Engineering at the University of California, and Professor Ray K. Linsley of Stanford University. They concurred in the conclusions of department personnel that inadequacy and errors of the basic data prevented the method from being reliably used to relate Delta outflow to salinity incursion and make predictions of salinity conditions in the future with Delta Water Facilities in operation.

Glover Method. In collaboration with engineers of the Charles T. Main Company, staff personnel of the department wrote a program for the IBM 650 computer to perform mathematical computations for a method employed by Robert E. Glover to analyze salinity conditions in the Delta.

Mr. Glover, an engineer with the U. S. Bureau of Reclamation, wrote a paper on a method of computing transient salinity conditions in the Delta. The information used in perfecting this method was historical four-day salinity observations made by the department, results of office and hydraulic model studies conducted by the Bureau of Reclamation, and theoretical salinity diffusion equations.

Mr. Glover, in his analysis, used actual salinity incursion patterns in the Delta to compute the outflow from the Delta to reproduce such salinity patterns. With the computed outflows a monthly depletion of water from the Delta channels was derived and compared to estimated consumptive use. A set of constants, applicable to the Delta for the diffusion equation, was also determined.

In applying this method to finding a suitable salinity incursion-Delta outflow relationship, the data from the monthly channel depletions and constants for the diffusion equation were utilized. Historical salinity in ppm of total dissolved solids (TDS) from the Bureau of Reclamation salinity recorder records for the months of May through September 1955, from seven locations in Suisun Bay and the western Delta were used in this study. Using Delta outflows during the identical time period the object was to reproduce the salinity conditions in the Delta using the Glover method. This approach was also unsuccessful in reproducing historical salinity conditions, even after several changes were made in the value of the constants and the monthly depletions.

Delta Outflow For Salinity Control

If waters in the Delta are to be diverted directly from Delta channels for municipal and industrial process use, then an outflow to maintain low concentrations of saline waters is needed. If water is to be diverted for agricultural purposes, then a higher concentration of saline water can be allowed. If transport of good quality water across the Delta for export therefrom is the prime objective, than an outflow commensurate to accomplish that objective is necessary. In the Delta, water for these three purposes plus recreation, navigation, and other uses is needed. Therefore, because the uses of water in the Delta are various, the selection of an outflow for control of salinity becomes one of economics.

Minimum Outflow for Protection of the Delta

An outflow of 3,300 second-feet was recommended in Bulletin No. 27 as that required to provide salinity control in the Delta. The degree of control was 1,000 parts chlorides per million parts water, mean tidal cycle surface zone salinity, at a point 0.6 miles below Antioch. This degree and point of control was selected, at the time of publication of Bulletin No. 27, as the most economical to provide an adequate and usable supply of good quality water to the Delta. It was concluded that at times when the natural flow of the rivers was insufficient to provide an outflow of 3,300 second-feet these flows should be supplemented by releases of fresh water from upstream storage reservoirs. The facility proposed to provide the necessary storage of water for controlled releases, in addition to other multipurpose functions, was Shasta Dam and Reservoir.

Views of the State of California regarding salinity control in the Delta were given in Reference 5. The following statement is extracted from that report:

> "In order to control the advance of salinity, a supply of water flowing into the Delta must be provided sufficient in amount, first to take care of the consumptive use in the Delta and, second, an additional amount flowing into Suisun Bay sufficient to repel the effect of tidal action in advancing salinity. The studies show that the practicable degree of control by means of fresh water releases would be a control at Antioch sufficient to limit the increase of salinity at that point to a mean degree of not more than 100 parts of chlorine per 100,000 parts of water, with decreasing salinity upstream. In order to effect a positive control of salinity at Antioch to this desired degree, of flow of 3,300 second-feet in the combined channels of the Sacramento and San Joaquin Rivers past Antioch into Suisun Bay would be required."

In the authorization of the Central Valley Project, salinity control was considered a function of the project, and statements at various times concerning the project have considered salinity control for protection of the Delta as a basic function.

After Shasta Dam and Reservoir were constructed in 1944 by the Bureau of Reclamation as a part of the Central Valley Project, it was operated to provide salinity protection to the Delta. Because of the release of fresh water to supplement natural flows, CVP has prevented the incursion of salinity into about 95 percent of the Delta. The 5 percent of the Delta not protected from salinity of 1,000 parts chlorides is in the western portion, of which Sherman Island is the primary area. However, the project has aggravated salinity problems in areas below the vicinity of Antioch by storing late spring runoffs which otherwise would have flushed saline water lower into Suisun Bay.

Minimum Outflow for Operation of the Central Valley Project

The official position of the Bureau of Reclamation toward salinity control in the Delta was stated in a letter to the department in response to a request to the Regional Director to comment on Bulletin

No. 60 (Ref. 14) with respect to the assumption contained therein on the operation of the Central Valley Project for salinity control. In the letter the Regional Director stated "I consider that the obligations of the Central Valley Project are satisfied when a satisfactory quality of water is provided at the intake to the Contra Costa and Tracy Pumping Plant". The Bureau of Reclamation has concluded that under present conditions of upstream development and diversions from the Delta, satisfactory water can be assured at the project pumps by maintaining a computed minimum outflow of approximately 1,500 second feet. Under present operation of the Delta pumping facilities of the Central Valley Project, water exported from the Delta in the Contra Costa Canal is approximately 70,000 acre-feet per year at a peak rate of about 180 second-feet; and in the Delta-Mendota Canal it is approximately 1,360,000 acre-feet per year at a peak rate of about 4,150 second-feet.

The Bureau of Reclamation has thus expressed its opinion that the quality of water exported from the Delta is the prime consideration for salinity control therein. It is realized that operation in this manner does provide salinity protection for the Delta, but not to the extent recommended by the State in Bulletin No. 27.

Minimum Outflow for Operation of the Delta Water Facilities

Facilities for the Delta were designed for multipurpose functions. Among the functions of paramount importance were conservation of water supplies and salinity control to provide adequate quantity and quality of water for use in, and export from, the Delta. One thousand second-feet was outflow determined to be the minimum to accomplish these functions for each of the alternative projects for the Delta, except the Chipps

Island Barrier Project. Determination of this minimum outflow is discussed in Chapter V of this appendix.

With an outflow of 1,000 second-feet, the concentration of salinity in the lower reaches of the Delta will be higher than with 1,500 second-feet outflow, and the incursion will extend further upstream into the channels. The mean location of salinity of 1,000 parts chlorides will be about the center of Decker Island in the Sacramento River and the mouth of False River on the San Joaquin River. With Delta facilities constructed, however, this outflow will protect the water transported across the Delta from degradation by ocean salinity, will provide 90 percent, or 450,000 acres of the Delta with protection from salinities greater than 100 parts chlorides. Substitute water facilities will provide equivalent water supplies for agricultural, municipal, and industrial purposes to the remaining ten percent of the Delta located within the Western Delta.

Minimum Outflow to Meet Water Demands from the Delta Without Delta Water Facilities

To evaluate the benefits of water conserved by the Delta Water Facilities, an estimate of Delta outflow was needed if works in the Delta were not constructed and demands for quality water from the Delta were met. Such an estimate was made using the techniques of routing salt and water through the Delta. The premise of the study was that; the natural channels and the Delta Cross Cannel have limited capacity in transferring water from the Sacramento River system into the San Joaquin system, and when the San Joaquin River flow is low the additional water to supply the export demand at the southern part of the Delta must move through Threemile Slough and around the western tip of Sherman Island. If the concentration of saline water in the Western Delta is high, then the mixture of water arriving at the pumps would be contaminated with sea water and would not meet the standards recommended for water to be exported from the Delta. Taking into account (1) the quantity and quality of inflow water, (2) consumptive use in the Delta, (3) degradation of the water due to the Delta drainage, (4) distribution of flows in the Delta, and (5) demands for export water, the salt-routing technique was used to determine the outflow necessary to limit the concentration of sea water in the Western Delta so that flows moving to the pumps would be of good quality.

The many calculations for this study were performed on an electronic digital computer. Details of the study and a listing of the results are in the back-up data for this office report. A graphical presentation of the results is shown on Plate 18, "Relationships of Delta Outflow to Rate of Export Pumping from Southern Delta". Each curve on the graph is for a different rate of consumptive use in the Delta, and the quality of water exported was estimated at 100 ppm chlorides, the concentration of chloride recommended by a board of consultants (1955) for the department for water quality objectives of water exported from the Sacramento-San Joaquin Delta. Other factors used in the development of these curves were (1) Sacramento River inflow water quality, 15 ppm chlorides; (2) San Joaquin River inflow rate, 500 second-feet and quality 200 ppm chlorides; and (3) flow to pumps from Western Delta, 1/5 through Threemile Slough and 4/5 around lower Sherman Island. Consequently, if a total export of water from the Southern Delta of 14,950 second-feet is made, consisting of 10,000 second-feet by the State in its San Joaquin Southern California Aqueduct, 4,600 second-feet by the Bureau of Reclamation in the Delta-Mendota Canal, and 350 second-feet in the Contra Costa Canal, the outflow from the Delta necessary to provide water not to exceed 100 ppm chlorides with a Delta consumptive use of 5,000 second-feet under the conditions set forth above is about 6,000 second-feet. The relationship shown on Plate 18 was thus used to make estimates of Delta outflow for present channel conditions and future demands for water from the Delta.

The quantity of stored water that would have to be released for control of salinity to enable the export of future quantities of water from the Delta was estimated for each 20-year condition of development. This was done from operation studies using a 20-year period of water supply, as discussed in Chapter IV of this appendix by determining the quantity of stored water which as part of the total outflow from the Delta for project operations. The quantity of stored water necessary for salinity control to meet future export demands with the existing channel system, is shown on the chart on page 45 of Bulletin No. 76.

CHAPTER IV. WATER RESOURCES

Discussions in this chapter include: (1) the supply of water to the Delta, (2) the utilization of water in the Delta, and (3) the outflow of water from the Delta. These three aspects are examined for natural, historic, present, and future conditions of development within the Delta and upstream watershed areas for identical water supply conditions. The four conditions of development are compared by using the 20-year water supply conditions of 1921-22 to 1940-41.

Supply of Water to the Delta

Water supply to the Delta consists of surface runoff from drainage basins in the Central Valley and precipitation in the Delta. Subsurface inflow into the Delta islands from adjacent ground water basins does not appear to be appreciable. These three sources of water supply are discussed in the ensuing paragraph.

Surface Inflow to the Delta

The Sacramento-San Joaquin Delta is the outlet of the Central Valley to the saline bays, and thence the Pacific Ocean, and receives its supply of water from the entire Central Valley Drainage Basin. The Sacramento River Basin, with an area of approximately 26,000 square miles lying north of the Delta, produces the greater portion (about 70 percent) of the flows arriving in the Delta. Its major tributaries originating in the Sierra-Nevada are the Feather, Yuba, and the American Rivers. Stony, Putah, and Cache Creeks located on the west side of the basin draining the coast range are generally intermittent in flow. These are the more productive streams, in terms of runoff, from the west side. The Goose Lake Basin which lies within the Sacramento River Drainage Basin contributes flow to the Sacramento River Basin only during periods of extreme high flow.

The San Joaquin River Basin has a total area of 16,000 square miles, excluding the Tulare Lake area. Principal tributaries of the San Joaquin River are the Merced, Tuolumne, Stanislaus, and Mokelumne Rivers. These streams all drain the westerly slopes of the Sierra Nevadas and flow westerly into the basin. The west side streams draining the easterly slopes of the coast range on the west side of the San Joaquin River Basin are extremely intermittent in flow and produce a small percentage of the total runoff from the basin. In times of high runoff flows from Tulare Lake Basin spill through Fresno Slough into the San Joaquin River.

Records of stream flow on the major tributaries to the main rivers draining the Central Valley are available for various periods of time. Records of flow for many of the smaller streams also have been maintained for brief lengths of time. First records of stream flow in the Central Valley were obtained by former State Engineer, William Ham Hall. Later records of stream flow are available in publications of the U. S. Geological Survey. As of September 30, 1947, records from 96 stream gaging stations located in the Sacramento River Basin and 105 stream gaging stations in the San Joaquin River Basin have been available. Considerable information as to the name, location, and elevation of stream gaging stations in the Central Valley have been published in Bulletin No. 1 (ref. 35). In this publication the period, source, and type of record are listed. Use of these records was made in the development of natural runoff from the Central Valley to the Delta.

Precipitation records within the Central Valley also have been maintained for various periods of time. Precipitation stations with records of 10 years or more are also listed in Bulletin No. 1. Use was made of precipitation records in determining stream flow to the Delta for areas in which stream gaging stations were not available. For areas in which neither precipitation records nor stream gaging records were available, a method of correlation between the particular drainage basin and similar drainage basins was used to determine flows therefrom.

Locations at which inflows to the Delta are measured are shown on Plate 19, "Central Valley Drainage Basins", and are tabulated in Table 6. Based on historical records from October 1921 through September 1957, flow of the Yolo Bypass near Woodland accounted for approximately 10 percent of the flow, Sacramento River at Sacramento for approximately 67 percent, and San Joaquin River near Vernalis for 16 percent, totaling 93 percent of the total Delta inflow. The other 10 stations have contributed the remaining 7 percent of flow.

TABLE 6

SACRAMENTO-SAN JOAQUIN DELTA INFLOW MEASURING STATIONS

Number	Name	Approximate percent total Delta inflow
1	Putah Creek near Davis (formerly at Winters)	--
2	Yolo Bypass near Woodland	10
3	Flow over the Sacramento Weir	--
4	Sacramento River at Sacramento	67
5	Cosumnes River at McConnell (formerly Michigan Bar)	--
6	Dry Creek near Galt	--
7	Mokelumne River at Woodbridge	--
8	Calaveras River near Stockton (formerly at Jenny Lind)	--
9	Stockton diverting canal at Stockton (formerly Calaveras River at Jenny Lind)	--
10	San Joaquin River near Vernalis	16
11	Bear Creek near Lockeford (measured since 1955)	--
12	Duck Creek near Stockton (measured since 1955)	--
13	French Camp Slough near French Camp (measured since 1955)	--

NOTE: Stations with undesignated percentages total 7 percent of total Delta inflow.

Factors Influencing Surface Inflow to the Delta. Factors which play an important role in determining the flow arriving at the Delta from the Central Valley are (1) variation in stream flow, (2) exports of water from the Central Valley upstream from the Delta, (3) use of water upstream from the Delta, (4) power generation and reservoir storage, and (5) importation of water into the Sacramento and San Joaquin Basins.

(1.) Variation in Stream Flow. Variation in surface inflow is the largest factor affecting runoff to the Delta. In addition to annual fluctuations in surface inflow there are seasonal fluctuations. July through October are months of low runoff, while December through May are months of high flow. Flows in June and November are somewhat intermediate between the extremes, their magnitude depending largely upon the wetness of the season. In Table 7, the estimated maximum, minimum, and mean monthly inflows to the Delta under natural conditions for the period 1921-22 to 1940-41 are tabulated.

TABLE 7

ESTIMATED MAXIMUM, MINIMUM, AND MEAN NATURAL INFLOW TO THE DELTA FOR WATER YEARS 1921-22 THROUGH 1940-41

(Units 1,000 acre-feet)

Month	Maximum	Minimum	Mean
October	545	332	447
November	2,525	353	824
December	6,293	455	1,735
January	6,024	662	2,080
February	8,688	738	3,845
March	10,599	756	3,816
April	7,907	1,260	4,266
May	9,044	1,298	4,272
June	6,166	504	2,600
July	2,360	349	993
August	922	297	499
September	617	281	406

A casual inspection of Table 7 shows that variations were the rule, with an extreme variation in monthly inflow in September of 281,000 acre-feet, and March with an inflow of 10,599,000 acre-feet. In fact, it was not uncommon for the flow in an individual month, (such as March 1938), of a wet year to exceed the entire annual flow in a dry season, such as 1923-24 and 1930-31.

Because of wide fluctuations in runoff from the Central Valley Drainage Basin, inflow to the Delta also fluctuates. To determine the availability of water in the Delta, a period of serveral years must be examined so that the irregularities of an individual year are not given more consideration than other years.

The water supply study period selected for analyses was the 20-year period commencing October 1921 and extending through September 1941. Within this study period is included the most severe drought period of record, 1927-28 through 1934-35, and the near maximum seasonal flow of the 1937-38 season. This 20-year period also includes the dryest years of record, namely, 1924 and 1931.

Estimates of stream flow are used to compare the availability of water within channels of the Sacramento-San Joaquin Delta for various conditions of historic and future development. The appropriateness of the selected study period is substantiated by the fact that the selected 20-year period has a water supply about 85 percent of the long-term 50-year period, water years 1907-08 to 1956-57.

Another factor influencing the selection of the 20-year period was that the department has utilized this period in developing water supply data for other California water resources development investigations. The Bureau of Reclamation has also employed this period in their studies of water supply in the Central Valley.

(2.) Exports of Water From the Central Valley Upstream From the Delta. Exports of water from the Central Valley is another factor which influence the amount of runoff from the Central Valley reaching the Delta. Two notable examples of such exportation of water from the San Joaquin River Basin are those of the East Bay Municipal Utility District, and the City of San Francisco.

One of the first exports of water from the Central Valley was that of the East Bay Municipal Utility District (EBMUD). Their supply is taken from the Mokelumne River and is transported by pipelines from Pardee Reservoir across the Delta to the east Bay area. The EBMUD began water deliveries to the east bay in June of 1929 and from 1930 to 1942 exports have risen to somewhat over 100,000 acre-feet per year with a maximum of 127,000 acre-feet in 1948-49.

The second exportation of water out of the basin was by way of Hetch Hetchy Aqueduct from Tuolumne River for eventual use by the City of San Francisco. Deliveries of water from the Tuolumne River system commenced in 1934. In early years exports varied from 2,000 to 50,000 acre-feet per year and from 1945 to date have exceeded 56,000 acre-feet annually with a maximum of 123,000 acre-feet in 1954-55. As both of these exports were relatively small, compared to total Delta inflow their effect on runoff to the Delta was slight. Interbasin transfer of water by operations of the Central Valley Project are not considered as exports from the valley.

(3.) Use of Water Upstream from the Delta. Use of water in the Central Valley also effects the surface inflow to the Delta. Continued development of agricultural, municipal, and industrial endeavors gradually required greater quantities of water in upstream areas, resulting in smaller flows to the Delta, particularly in summer months. This gradual reduction in Delta water supply became of such magnitude in the dry seasons of 1918 and 1924 as to be readily apparent to Delta water users. Considerable reduction in summer flow during dry years persisted until Shasta Reservoir commenced operations in 1944. Inflow to the Delta from the Sacramento and San Joaquin Rivers will probably continue to be reduced by increasing requirements for water within the drainage basin.

The "County of Origin" law requires that future demands for water within a local area must have priority over requirements in other areas. In estimating future consumptive use it was assumed that supplies would be developed to the extent necessary to meet all estimated requirements.

In an office report (Reference 25) compiled by the Economics Unit of the department, consumptive use in the entire valley, including the Delta, at future conditions of development was estimated as shown in Table 8.

TABLE 8

ESTIMATED DEPLETION OF INFLOW
TO THE DELTA BY UPSTREAM WATER USERS[1]

Year	Annual depletion, in millions of acre-feet[2]
1900	1.1
1920	3.1
1940	5.8
1955 (present)	7.4
1970	8.3
1980	9.5
1990	10.9
2000	12.0
2020	13.6

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[1] Present conditions defined under the section of this chapter on "Outflow from Delta".

[2] Depletions include those of several areas of the Central Valley Project upstream from the Delta.

(4.) Power Generation and Reservoir Storage. Power generation and reservoir storage is another factor which influences the inflow of water to the Delta. In general, water is stored in high flow months to be released during periods of low flow. Power releases tend to regulate natural flows by supplementing flows during low runoff periods.

Prior to construction of Shasta Dam and Reservoir about 50 percent of the total storage capacity in all reservoirs in the Central Valley was utilized for power purposes. Since Shasta Dam, however, the percentage of storage capacity utilized for power purposes has decreased to about 25 percent of total storage. Shasta Dam and Reservoir are units of a multipurpose project, and power development is an integral part of its operation. With further integration of Bureau of Reclamation facilities and coordination with state facilities, the separation of the effect of a single-purpose power or water conservation operation will become more difficult to evaluate.

(5.) Importation of Water into Sacramento-San Joaquin River Basins. Importation of water into the Central Valley basins is the fifth factor affecting surface inflow to the Delta. In the immediate future, the Bureau of Reclamation will bring water from the Trinity River into the Sacramento River system. These imports of water will augment the flow reaching the Delta unless diverted for prior use. Under operation of the proposed State Water Facilities, additional water will be imported from north coast streams by developing projects for that purpose. These imports will also effect runoff arriving at the Delta. The quantity of water expected to be imported from streams on the north coast, and the dates those quantities are expected to be needed, are listed later in this chapter.

From the discussion of the factors which influence flows arriving at the Delta it can readily be seen that availability of water in the Delta depends on several factors other than export of water from the Delta.

Natural Inflow to the Delta. For purposes of this study natural conditions are defined as those in existence before any significant agricultural, municipal, or industrial development in the Sacramento and San Joaquin Valleys. Natural conditions can be considered to be quite similar to the condition of development which was prevalent about 1850. In 1850 very few, if any, of the streams were leveed, channel rectifications had not been made, and agricultural development had not yet commenced. Early publications were consulted to find descriptions of the natural topography of the Sacramento and San Joaquin River Basins.

Under natural conditions the Sacramento River built up small natural levees on each side of its banks. It is noted, however, that these levees were not continuous, but crevasses or breaks were located at various points within the basin. Lands adjoining the river were higher than the lands at some distance from the river, there being a gradual slope from the river to the low point of the basin. Basins adjoining the rivers were great saucer-like areas which in times of flood became filled with water. Tule growths were quite prevalent in these basins.

In times of flood the San Joaquin River also spread out over considerable area but not to the same extent as the Sacramento River in the Sacramento Basin, primarily because the quantities of flood runoff did not approach the magnitude of flood flows in the Sacramento River.

The Delta region, located at the confluence of Sacramento and San Joaquin Rivers, under natural conditions was at or near sea level and was composed of numerous islands with hundreds of miles of interconnecting channels and sloughs. The Delta region particularly was covered with dense stands of tules and other luxuriant growth which consumed considerable quantities of water.

Determination of natural flows to the Delta was made for the selected 20-year period, 1921-22 to 1940-41. In the computations, historic stream gaging records were modified to reflect historic consumptive use, diversions, and regulation in the basin. To simplify the computations of natural runoff the basin was considered in three parts. The first part was the area lying above the valley floor, which is the principal source of all flows from the basin to the Delta. Precipitation in this area generally is of greater magnitude than in other areas of the basin and much of the precipitation falls as snow and is retained as natural storage for subsequent runoff during warmer months. The second part was that of the valley floor below the foothill stations and above the Delta. The third part was the Delta region itself. Evaluation of each of these areas in affecting flows to the Delta are considered separately.

The first step in computing natural flow was the collection of all available measurements of stream flow at foothill stations of various tributaries to the Sacramento and San Joaquin Rivers. The stations were generally located above the valley floor and were separated into 37 separate segments of the Central Valley Basin. Each segment was then carefully examined to determine the amount of runoff that it contributed to the total flow on a monthly basis. These 37 segments include some 30,000 square miles of drainage area. The location of these segments are shown on Plate 19. Segments of the valley utilized in this investigation, their approximate average annual runoff, and the method used in determining natural runoff, are shown in Table 9.

Records of historic stream flow were available for 83 percent of the drainage area covered by the 37 segments. Natural flow was determined by modifying measured historic flows by historic diversions, return flow, and effects of reservoir regulation. In the remaining 17 percent of the area above the valley floor two methods were used for estimating monthly natural flow. For 13 percent of the area, natural runoff was obtained by correlation with known natural runoff computed from historical records of a similar drainage basin. For 4 percent of the area, runoff was developed from historic precipitation occuring in the area. In this method, engineering judgment as to the natural amount of consumptive use, ground water storage changes, and infiltration was relied upon to determine the runoff. Summation of monthly flows from each of the 37 segments is the quantity of natural flow contributed by the area above the foothills.

The next question to consider was the effect the valley floor would have on these flows as they passed downstream to the Delta. Would the flows be increased or decreased in passing through the valley floor? Several attempts to evaluate what would happen to these flows while on the valley floor were made using different assumptions. One assumption was that the monthly quantities of runoff from the foothills would pass through the valley unchanged in magnitude or distribution. Thise assumption implies that natural consumption within the valley would equal the precipitation within the valley. It is obvious that this assumption is a simplification of what actually occurred in any particular month, or along any particular stream. It is believed, however, that the monthly flow leaving the valley floor and entering the Delta under this assumption would be reasonable. In view of the complexities of refining estimates of natural flows, it is believed that this assumption is adequate for this investigation. Thus computed natural flows at the foothill stations above the valley floor were assumed to be the natural inflows to the Delta. Natural inflows to the Delta for the 20-year period, 1921-22 water year to 1940-41 water year are shown in Table 10. The average annual inflow to the Delta for the 20-year period was about 25,800,000 acre-feet. Converting the average annual inflow for the 20-year period to the 50-year or long-term mean, (1907-08 to 1956-57) would give a natural annual inflow to the Delta of about 30,300,000 acre-feet.

Historical Inflow to the Delta. In addition to determining natural flows entering the Delta, historic inflows on a monthly basis were also determined. Recorded flows at the 13 Delta inflow stations, listed in Table 6, were summarized from "Reports of Sacramento-San Joaquin Water Supervision". Total monthly flows are listed in Table 11 for water years 1921-22, through 1957-58. Flows are listed in thousands of acre-feet on a monthly basis. Stations 11, 12, and 13 were not measured until 1955, but prior to then an estimate of return flow from the diversions to the Delta uplands was added to the other measured flows to obtain total inflow to the Delta.

Present Inflow to the Delta. Present inflow is defined as the inflow to the Delta that would have occurred if present developments and

TABLE 9

SEGMENTS OF CENTRAL VALLEY DRAINAGE BASIN CONTRIBUTING FLOW TO THE SACRAMENTO-SAN JOAQUIN RIVER SYSTEM

Segment No.	Stream and Gaging Location	Approximate average annual flow in 1,000 A.F.	Method used in determining natural runoff[1/]
1	Putah Creek near Winters	328	A
2	Cache Creek near Capay	416	C
3	Unmeasured streams, Cache Creek to Stony Creek, above 500 foot contour	205	C
4	Stony Creek at Canyon Mouth	265	A
5	Thomas Creek at Paskenta	180	A
6	Unmeasured streams in Thomas Creek drainage area above 500 foot contour	59	C
7	Elder Creek near Henleyville	70	A
8	Redbanks Creek group	94	C
9	Sacramento River at Red Bluff	7,002	A
10	Antelope Creek group	172	C
11	Mill Creek near Los Molinos	186	C
12	Dear Creek near Vina	195	A
13	Chico Creek near Chico	88	C
14	Butte Creek near Chico	218	A
15	Unmeasured streams, Mill Creek to Feather River, above 500 foot contour	187	C
16	Feather River near Oroville	3,753	A
17	Yuba River at Smartsville	2,066	A
18	Bear River near Wheatland	289	A
19	Unmeasured streams, Feather River to American River, above 500 foot contour	170	C
20	American River above Fair Oaks	2,289	A
21	Cosumnes River at Michigan Bar	302	A
22	Dry Creek at Ione	66	A
23	Mokelumne River at Mokelumne Hill	631	A
24	Unmeasured streams, American River to Calaveras River above 500 foot contour	71	C
25	Calaveras River at Jenny Lind	140	A
26	Unmeasured streams, Calaveras River to Stanislaus River, above 500 foot contour	26	C
27	Stanislaus River below Melones power house	988	A
28	Tuolumne River at La Grange	1,677	A
29	Unmeasured streams, Stanislaus River to Merced River, above 500 foot contour	44	C
30	Merced River at Exchequer	893	A
31	Unmeasured streams, Merced River to Chowchilla River, above 500 foot contour	104	C

Table 9 continued

Segment No.	Stream and Gaging Location	Approximate average annual flow in 1,000 A.F.	Method used in determining natural runoff[1]
32	Chowchilla River at Buchanan	70	A
33	Fresno River near Daulton	69	A
34	Unmeasured streams, Chowchilla River to San Joaquin River, above 500 foot contour	13	C
35	San Joaquin River at Friant	1,577	A
36	Inflow to San Joaquin Valley from Tulare Lake Basin	749	C
37	Inflow to San Joaquin Valley from the west side	115	B
	Total	25,767	

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[1] A = Determined by modifying measured historic flows by measured historic diversion, return flows and storage regulation.

B = Computed from historic precipitation records, estimated consumptive use and soil moisture changes.

C = Determined by correlation with similar segments of known natural runoff.

TABLE 10

ESTIMATED NATURAL DELTA INFLOW
in 1,000 acre-feet

Water Year	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1921-22	458	561	1,571	1,446	3,940	3,280	4,600	8,240	5,830	1,664	680	481	32,751
23	522	923	3,166	2,488	1,638	1,891	4,291	4,497	2,482	1,314	576	518	24,306
24	545	493	544	662	1,430	756	1,260	1,308	504	401	321	298	8,522
1924-25	436	989	1,236	1,210	6,843	2,774	4,889	4,709	2,528	1,051	572	447	27,684
26	483	604	820	1,029	4,300	2,116	5,043	2,633	1,065	558	387	349	19,387
27	391	2,525	2,467	2,897	8,688	4,667	6,207	5,212	3,769	1,357	603	471	39,254
28	476	1,783	1,334	1,690	2,638	7,745	4,677	3,583	1,382	679	451	393	26,831
29	386	607	815	755	1,420	1,537	1,930	2,981	1,717	644	359	328	13,479
1929-30	332	353	2,983	1,886	2,361	3,588	3,201	2,747	1,899	686	414	383	20,833
31	404	515	455	984	943	1,442	1,463	1,421	620	349	297	281	9,174
32	375	449	2,393	1,780	2,698	3,025	3,261	4,988	3,628	1,289	504	368	24,758
33	350	377	487	888	738	2,276	2,366	2,874	3,001	777	388	328	14,850
34	369	406	1,384	1,840	2,032	2,307	1,941	1,298	769	406	325	286	13,363
1934-35	370	1,041	976	2,640	1,997	2,968	7,907	5,728	3,522	1,028	508	376	29,061
36	449	465	606	4,111	7,381	3,569	4,816	4,552	2,873	1,086	505	381	30,794
37	392	383	583	712	3,559	4,474	4,775	6,087	2,953	1,019	473	373	25,783
38	466	2,124	6,293	2,425	7,873	10,599	7,653	9,044	6,166	2,360	922	617	56,542
39	707	761	950	946	1,023	2,349	2,738	1,796	864	492	375	394	13,395
1939-40	502	411	813	5,197	8,008	8,222	5,803	4,607	2,296	819	488	441	37,607
41	522	717	4,814	6,024	7,395	6,742	6,491	7,133	4,135	1,886	832	599	47,290
Total	8,935	16,487	34,690	41,610	76,905	76,327	85,312	85,438	52,003	19,865	9,980	8,112	515,664
Average	447	824	1,735	2,080	3,845	3,816	4,266	4,272	2,600	993	488	406	25,783

TABLE 11

HISTORIC DELTA INFLOW

(In 1,000 acre-feet)

Water Year	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1921 - 22	522	558	1,482	1,553	4,037	3,325	3,946	5,334	3,938	1,041	342	402	26,480
23	578	875	3,093	2,548	1,650	1,540	3,506	2,673	1,499	664	306	429	19,361
24	634	526	595	709	1,396	588	681	371	117	85	113	189	6,004
25	374	808	1,113	1,115	6,607	2,326	4,182	1,341	1,533	466	243	348	20,456
26	529	633	876	1,033	4,345	1,708	3,693	1,405	390	171	165	329	15,277
27	466	2,181	2,337	2,745	8,610	4,502	5,417	3,424	2,245	613	318	401	33,259
28	570	1,468	1,365	1,713	2,501	7,055	4,009	2,069	625	315	240	374	22,304
29	494	704	838	891	1,466	1,285	1,232	1,285	700	236	216	338	9,685
30	432	428	2,299	2,023	1,862	3,470	2,146	1,514	765	277	240	418	15,874
1930 - 31	546	596	620	972	890	1,064	524	313	153	31	65	201	5,975
32	299	419	1,508	2,126	2,325	2,202	2,060	3,002	2,177	656	226	275	17,275
33	365	403	592	889	937	1,609	1,489	1,360	1,302	265	156	277	9,644
34	399	517	1,043	2,003	1,631	1,728	1,096	508	263	120	118	232	9,658
35	337	843	799	2,742	1,677	2,961	6,861	4,169	2,295	492	270	362	23,608
36	559	567	726	3,820	6,794	3,965	3,712	3,000	1,892	511	267	385	26,199
37	475	487	631	817	3,375	4,816	4,212	3,835	1,988	478	205	329	21,648
38	592	2,068	5,433	2,592	8,718	11,555	7,347	7,033	4,987	1,620	560	533	53,038
39	733	889	1,136	1,051	1,099	1,636	1,251	636	243	128	133	331	9,266
40	443	428	727	3,995	5,715	8,481	7,375	2,977	1,438	370	259	449	32,657
1940 - 41	537	769	3,767	7,185	7,588	7,757	6,718	5,104	2,955	1,150	434	436	44,400
42	598	749	3,755	5,430	8,655	3,024	5,131	4,467	3,521	1,103	377	485	37,345
43	638	995	1,916	5,480	4,406	6,910	4,431	2,959	1,760	468	297	408	30,668
44	630	677	782	948	1,800	2,223	1,265	1,732	791	283	265	406	11,802
45	447	1,044	1,456	1,294	4,406	2,456	2,288	2,665	1,674	676	530	614	19,550
46	772	1,234	4,570	4,957	1,773	2,050	2,442	2,607	1,120	527	502	606	23,160
47	669	941	1,342	1,002	1,558	2,135	1,607	811	570	351	386	496	11,868
48	668	813	678	1,579	815	1,306	3,586	3,806	2,735	706	576	697	17,965
49	730	771	925	891	933	3,689	2,146	1,843	788	438	481	562	14,197
50	527	633	625	1,820	3,006	2,197	2,810	2,349	1,483	548	492	604	17,094
1950 - 51	723	4,202	8,069	4,803	5,037	3,310	1,887	2,276	884	593	647	680	33,111
52	724	961	2,931	6,4[illegible]8	5,974	5,301	6,214	6,659	4,151	1,396	794	801	42,296
53	753	791	2,404	7,103	2,198	1,740	1,965	2,533	2,299	802	598	808	23,994
54	783	943	1,030	1,964	4,017	3,669	3,618	2,040	750	541	616	731	20.702
55	742	1,002	1,789	1,818	1,058	938	932	1,445	825	581	584	632	12,346
56	846	681	7,525	11,563	5,687	4,051	2,458	3,796	2,407	1,008	851	948	41,821
57	913	1,042	971	917	1,392	3,979	1,342	2,232	1,331	638	656	811	16,224

regulation of flow had been operating during the selected 20-year study period. Presentinflows to the Delta were not determined directly. They were derived in the following manner: Infow on a monthly basis equals Delta outflow plus consumptive use in Delta lowlands, plus net diversions to Delta uplands, plus exports from the Delta, less precipitation in Delta lowlands. Present monthly inflows with, 3,300 second-feet minimum outflow are tabulated in Table 12, and monthly inflows with 1,500 second-feet minimum outflow are tabulated in Table 13. Methods used to develop present monthly outflows are covered later in this chapter.

Future Inflow to the Delta. Future inflow to the Delta was estimated for each condition of development. The method used to determine future inflows was the same as outlined above to find inflow for present conditions. In addition to determining the total inflow to the Delta, a breakdown of the inflow was made for each of the Delta inflow streams for 1970 and 1990 conditions of development. This information was used in making water quality estimates, which are discussed in Chapter VI of this appendix. The estimated 1990 Delta inflow is tabulated in Table 14 on a calendar-year basis rather than a water-year basis, as for present conditions. A tabulation of other future inflows to the Delta are not included in this report, but are on file in the back-up data for this report.

Precipitation on the Delta

Another source of water supply to the Delta is precipitation. In a normal year this amounts to about 14 inches. Rainfall recorded at the gage located at Benson's Ferry, about 4 miles east of Walnut Grove near the Mokelumne

TABLE 12

ESTIMATED PRESENT DELTA INFLOW WITH
3,300 SECOND FEET MINIMUM DELTA OUTFLOW
in 1,000 acre-feet

Water Year	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1921-22	693	687	1,237	1,176	3,173	2,579	2,587	3,919	2,898	880	713	769	21,311
23	860	1,071	2,854	2,501	1,417	1,170	2,529	1,887	1,144	735	713	708	17,589
24	629	589	893	753	1,139	570	619	513	606	735	709	618	8,373
25	543	587	845	788	5,169	1,727	2,304	2,051	1,008	740	711	684	17,157
26	551	554	834	891	4,455	1,250	2,202	942	618	742	716	644	14,399
27	561	1,302	2,018	2,354	8,507	3,481	3,840	2,625	1,617	738	715	744	28,502
28	733	1,489	1,216	1,669	2,498	6,395	3,085	1,720	618	738	715	587	21,463
29	532	573	868	792	1,318	801	741	719	654	740	716	572	9,026
30	513	475	1,773	1,488	1,840	2,785	1,473	1,099	673	742	715	602	14,178
1930-31	570	537	557	726	711	765	535	505	601	745	718	603	7,573
32	539	511	1,097	1,570	1,688	1,348	1,288	2,139	1,818	740	713	595	14,046
33	467	519	851	725	761	762	859	806	1,063	740	715	530	8,798
34	493	498	803	1,341	1,342	1,187	755	526	606	743	714	557	9,565
35	510	638	817	1,897	1,272	2,146	5,466	3,389	1,726	740	715	587	19,903
36	560	509	816	3,536	6,841	3,130	2,470	2,347	1,642	745	715	577	23,888
37	507	457	801	663	2,698	4,028	3,311	3,128	1,517	743	715	563	19,131
38	543	2,275	5,337	1,968	8,259	9,697	6,167	6,288	3,759	1,142	713	703	46,851
39	1,099	863	1,135	942	1,072	1,458	866	630	610	742	711	585	10,713
40	564	490	522	3,166	5,285	6,896	5,970	2,378	1,185	741	712	657	28,566
1940-41	576	621	4,126	6,821	7,142	6,023	5,555	4,239	2,039	840	712	636	39,330
TOTAL	12,043	15,245	29,400	35,767	66,587	58,198	52,622	41,850	26,402	15,451	14,276	12,521	380,362
Average	602	762	1,470	1,788	3,329	2,910	2,631	2,093	1,320	773	714	626	19,018

TABLE 13

ESTIMATED PRESENT DELTA INFLOW WITH 1,500 SECOND FEET MINIMUM DELTA OUTFLOW
in 1,000 acre-feet

Water Year	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1921-22	693	687	1,237	1,176	3,173	2,579	2,587	3,919	2,898	880	608	769	21,206
23	965	1,071	2,854	2,501	1,417	1,170	2,529	1,887	1,144	624	602	708	17,472
24	652	589	893	753	1,191	591	619	472	499	624	604	618	8,105
25	543	587	881	847	5,564	1,727	2,304	2,051	1,008	629	600	684	17,425
26	551	554	834	891	4,677	1,250	2,202	942	513	631	605	644	14,294
27	561	1,377	2,106	2,466	8,559	3,481	3,840	2,625	1,617	710	604	744	28,690
28	737	1,624	1,216	1,669	2,498	6,395	3,035	1,720	618	627	604	587	21,380
29	532	573	868	792	1,318	801	741	936	659	629	605	572	9,026
30	513	475	1,773	1,619	1,926	2,790	1,473	1,099	673	631	604	602	14,178
31	570	537	557	726	711	765	535	482	494	634	607	603	7,221
32	539	511	1,198	1,732	1,938	1,409	1,288	2,139	1,818	682	602	595	14,451
33	467	519	851	725	761	762	859	975	1,063	629	604	485	8,700
34	493	498	803	1,409	1,464	1,251	755	513	499	632	603	557	9,477
35	510	638	817	1,897	1,360	2,294	5,585	3,389	1,726	631	604	579	20,030
36	560	509	816	3,764	6,841	3,130	2,470	2,347	1,642	634	604	577	23,894
37	507	457	801	663	2,920	4,028	3,311	3,128	1,517	668	604	557	19,161
38	543	2,348	5,456	1,968	8,259	9,697	6,167	6,288	3,759	1,142	641	703	46,971
39	1,171	863	1,135	942	1,072	1,458	866	630	504	631	600	585	10,457
40	564	490	522	3,476	5,303	6,896	5,970	2,378	1,185	630	601	657	28,672
41	576	621	4,348	6,821	7,142	6,023	5,555	4,239	2,039	840	604	636	39,444
TOTAL	12,247	15,528	29,966	36,837	68,094	58,497	52,741	42,159	25,875	13,738	12,110	12,462	380,254
Average	612	776	1,498	1,842	3,405	2,925	2,637	2,108	1,294	687	606	623	19,013

TABLE 14

Estimated 1990 Delta Inflow
With 1,000 Second-feet Minimum Delta Outflow
(Thousands of Acre-feet)

Water Year	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1922	662	362	224	1,183	3,130	2,650	1,910	3,513	2,684	1,648	1,579	1,143	20,688
23	645	289	1,903	2,334	1,382	985	2,088	1,389	1,345	1,648	1,579	1,129	16,716
24	651	375	304	279	293	520	743	881	1,133	1,374	1,311	1,011	8,875
25	594	356	209	301	2,299	1,280	1,788	1,605	1,352	1,653	1,577	1,143	14,157
26	659	373	281	254	2,896	896	1,572	1,076	1,356	1,655	1,582	1,147	13,747
27	628	245	315	1,787	7,877	3,188	2,957	2,077	1,399	1,651	1,581	1,143	24,848
28	625	342	354	1,650	2,324	6,262	2,484	1,072	1,356	1,651	1,581	1,145	20,846
29	667	324	270	305	312	515	838	1,084	1,306	1,653	1,582	1,143	9,999
30	665	383	249	189	1,030	2,200	886	1,070	1,352	1,655	1,581	1,137	12,397
31	649	373	322	234	302	532	720	825	1,058	1,310	1,250	967	8,542
32	612	353	139	293	240	562	828	1,061	1,351	1,653	1,579	1,143	9,814
33	668	379	286	230	327	514	757	866	1,137	1,379	1,317	1,012	8,872
34	612	382	218	288	232	579	816	1,024	1,274	1,582	1,510	1,084	9,601
35	639	314	283	189	331	1,612	4,161	2,396	1,355	1,653	1,581	1,144	15,658
36	645	373	277	1,650	6,127	2,580	1,555	1,439	1,344	1,658	1,581	1,122	20,351
37	656	383	252	229	1,212	3,426	2,869	2,348	1,345	1,656	1,581	1,143	17,100
38	659	320	4,231	1,773	8,073	9,580	5,809	5,878	3,368	1,652	1,579	1,138	44,060
39	643	376	408	926	1,027	1,295	856	1,047	1,348	1,655	1,577	1,131	12,289
40	654	381	314	88	3,980	6,478	5,187	1,738	1,352	1,654	1,578	1,138	24,542
41	646	379	1,921	6,028	6,931	5,981	5,076	3,720	1,637	1,652	1,578	1,141	36,690
TOTAL	12,879	7,062	12,760	20,210	50,325	51,635	43,900	36,109	29,852	32,092	30,664	22,304	349,792
AVERAGE	644	353	638	1,011	2,516	2,582	2,195	1,805	1,493	1,605	1,533	1,115	17,490

River, was used as an indicator of the precipitation on the Delta lowlands. The amount of precipitation was determined as the recorded precipitation at Benson's Ferry, modified by the ratio of normal precipitation in the Delta to the normal precipitation at Benson's Ferry multiplied by the area of the Delta lowlands.

It was assumed that precipitation assists in satisfying consumptive use and in increasing outflow from the Delta. In summer months, however, rainfall is generally negligible.

Ground Water Accretions to the Delta

In Bulletin No. 60 (Ref. 14) an allowance of 500 second-feet throughout the year was made for ground water accretions to the Delta. Data gathered since the publication of Bulletin No. 60, and studies conducted by the staff of the Water Project Authority, indicate there is little if any ground water accretion to the Delta. Therefore, ground water accretions were not considered as an item of water supply to the Delta.

Utilization of Water in the Delta

Use of water in the Delta includes that estimated to be consumptively used by evapotranspiration of crops and vegetation; net irrigation diversions to Delta uplands, which are measured diversions less an estimated return flow; industrial use of process water by industries located within the Delta; and evaporation from water surfaces. The diversions of water from Delta channels by the Bureau of Reclamation for Contra Costa and Delta-Mendota Canals, diversion from Cache Slough by the City of Vallejo, proposed future diversions for the

Bureau's East Side Division, and proposed future diversions by the State into its water facilities to export water to areas of deficiency in the south, are demands that must also be satisfied.

Consumptive Use in Delta Lowlands

Diversions of water to islands of the Delta for irrigation are difficult to measure because diversions are made through siphons and pumps operating under continually fluctuating water levels in the channels. The majority of the islands are generally irrigated from siphon diversions from adjacent channels or by subsurface inflow. Because of tidal changes in water surface elevations, determination of the quantity and rate of diversion from the channels through the thousands of siphons becomes a momentous task. Even if siphon diversions could be adequately gaged, total inflow to the islands would not be measured because of water seeping from the channels into the islands. Therefore, to obtain an indication of the amount of water leaving the channels, an approach other than direct measurements was utilized. Such an approach was making estimates of the water consumed by crops and natural vegetation through evapotranspiration, and evaporation from bare and idle land and open-water surfaces.

Field experiments had been conducted in the Delta to determine unit values of consumptive use of water for the many crops grown in the Delta. These were made by tank experiments. The acreage of various crops were determined from crop surveys. Applying unit values of consumptive use to crop acreages, the monthly consumptive use of water in the Delta lowlands was determined. Consideration of channel depletion rather than consumptive use as an indication of water use in the Delta is discussed later in the chapter; however, use of channel depletion in the determination of outflow was not made in these studies.

Natural consumptive use in the Delta was estimated to determine the effect of the Delta on the flows passing through. Examination was made of early maps of the Sacramento-San Joaquin Delta area and an extensive review was made of early literature describing the Delta region. This information indicated that a considerable area in the Delta was afforded a supply of fresh water under natural conditions. The fresh-water supply supported a dense growth of high water-consuming vegetation, namely tules and other luxuriant growths. It is estimated that under natural conditions 180,000 acres were covered by dense tules, 120,000 acres were covered by other luxuriant natural vegetation, and 40,000 acres were almost always covered by water. In its original state of nature the Delta probably consisted of swamps and overflow lands gradually built up through the ages by accumulation of decayed vegetation and deposits of silt brought down by the Sacramento and San Joaquin Rivers. These swamps lands were at or near the elevation of mean sea level and were covered with various types of aquatic vegetation, trees, and grasses.

Based on data of consumptive use collected by the department, an average annual consumptive use of 5 acre-feet per acre was estimated as the natural requirement for the 340,000 acres having an available fresh-water supply. This rate of consumptive use gave a total requirement of 1,700,000 acre-feet per year. This total quantity was distributed on a monthly schedule of use applicable to the Delta area.

Present and future consumptive use in the Delta were also estimated. Periodic land use surveys of the Sacramento-San Joaquin Delta have been made since 1924. The acreage of the various types of crops and other types of culture within islands or tracts located within the Delta was determined by these surveys; the most recent being made in 1955. This survey showed 470,000 acres in the Delta lowlands, and classified 390,000 acres as agricultural land. The remaining acreage consisted of water surface areas, levees and berms, urban lands, tule and swamp lands. Estimates of present and future consumptive use in the Delta lowlands were based on the 1955 crop survey and unit consumptive use data collected by the department. In estimates of future consumptive use, allowances were made for anticipated increases in double cropping for this area. Table 15 shows estimated monthly consumptive use of water for natural, present, and future conditions in the Delta lowlands.

Channel Depletion in Delta Lowlands

As stated previously, channel depletion was not used in these studies as one of the items of water utilization, but is discussed because it may have merit at a later date when additional data on the hydrology of Delta islands are obtained. In making correlations of salinity incursion and outflow from the Delta, wide variations were found which could not be easily explained. Apparent similar salinity patterns could not be matched by corresponding computed outflows. This was also found by Robert E. Glover and pointed out in his paper (Ref 38). A possible explanation was that actual outflows from the Delta may have differed from computed outflows.

The difference between actual outflows and computed outflows could be that the depletion of water from the channels of the Delta is not the same as the consumptive use. Depletion of water from the channels consists of both direct diversions and seepage, and hereinafter will be referred to as channel depletion. Water used to satisfy consumptive use demands does not necessarily have to come from the channels immediately. Water previously stored in the soil can be utilized. If such is the case in the Delta, there

TABLE 15
ESTIMATED
CONSUMPTIVE USE IN DELTA LOWLANDS[1/]
(1,000 acre-feet)

Month	Natural	Present	1970	1980	1990	2000	2020
October	135	105	120	124	127	127	127
November	79	54	61	64	66	66	66
December	39	42	48	50	51	51	51
January	39	29	33	35	35	35	35
February	54	35	40	42	42	42	42
March	95	47	53	55	57	57	57
April	143	113	128	133	136	136	136
May	196	158	179	187	191	191	191
June	238	183	207	216	221	221	221
July	268	244	277	288	295	295	295
August	232	260	296	307	315	315	315
September	182	192	217	226	232	232	232
TOTAL	1,700	1,462	1,659	1,727	1,768	1,768	1,768

[1/] Includes all uses except industrial and municipal

should be changes in soil moisture and/or changes in the elevation of ground water in the islands. Such changes in the soil moisture content and in ground water elevations do take place, so consideration was given to the possibility that ground water storage, which is not constant throughout a year, does contribute to meeting consumptive use in the Delta. Therefore, in a given month the water seeping from the channels into the islands may be stored for later consumptive use by the crops.

Using the present method of computing outflow from the Delta the consumptive use is one of the uses subtracted from Delta inflow. On many occasions zero or negative outflows are computed in the summer months. Under such conditions salinity in the Delta should have reached excessive proportions. Since it did not, it is evident that the actual outflows were larger than computed, and that ground water storages were instrumental in satisfying consumptive use. Information from two sources was utilized to explore the possibility of ground water storage affecting channel depletion, and thus Delta outflows.

The first source of data were collected from May 1954 through October 1955 (Ref. 13). The drainage survey was carried out on 33 islands in the Delta lowlands, which comprise 46.4 percent of the total agricultural acreage.

The following hydrologic equation was used to determine changes in ground water storage:

$$C + Dr = P + Di + S \pm GWS$$

Consumptive use + drainage = precipitation + diversions
+ seepage ± change in ground water storage

Where consumptive use "C", designates the amount of water actually consumed through evaporation, transpiration by plant growth, and other processes, and drainage "Dr", represents excess water pumped from the islands into Delta channels. Values of drainage were compiled from office computations.1/ Precipitation "P", was obtained from precipitation data from several weather stations in the Sacramento-San Joaquin Delta. The acreage of the island, multiplied by the precipitation, gave the quantity of precipitation on the island.

1/ "Water Project Authority Delta Drainage Survey", Computation 30, Volume 10 (Backup Data to Ref. 13).

Diversions "Di", were determined for each island by multiplying the crop acreage by an applied water factor. Applied water factors were also taken from prepared office computations.[1/]

Seepage "S", and change in ground water storage "GWS", were obtained by solving the hydrologic equation.

A sketch depicting this equation is shown on Plate 20, "Seepage of Water from Channels into Delta Lowlands".

Since measurements or estimates were made for all quantities except seepage and change in ground water storage, the algebraic sum of these two terms could be determined. Accumulated values of seepage, plus or minus change in ground water storage for the study period May 1954 through October 1955, are plotted on the mass diagram of seepage and change in ground water storage on Plate 20.

The seepage rate depends upon the differential head between water elevations in exterior channels and water elevations in drainage ditches in the islands. The mean monthly differential head in most areas of the Delta is essentially constant throughout the year, varying not more than about 5 percent in any specific month. This constant differential head would indicate a rather uniform seepage rate. On the "Mass Diagram of Seepage and Change in Ground Water Storage" on Plate 20, a straight line can be drawn between any two points 12 months apart to represent a constant annual seepage rate. The straight line drawn or the mass curve for this study was from November 1, 1954 to October 30, 1955. It was assumed that the change in ground water storage in this 12-month period was zero.

1/ "Water Project Authority Delta Drainage Survey", Computation 32, Volume 11 (Backup Data to Ref. 13).

Monthly rates of change in ground water storage were determined by taking the difference between the slope on the mass curve for any one month and the slope of the seepage rate curve, (the straight line connecting November 1, 1954 and October 30, 1955). Mass curve slopes greater than the seepage rate curve indicate water leaving storage, and slopes less than the seepage rate curve indicate water entering ground water storage. A plot of the monthly changes in ground water for storage for the 33 islands is shown on the diagram "Monthly Change in Ground Water Storage" on Plate 20. Table 16 lists the estimated monthly rates of change in ground water storage for the 33 Delta islands and the entire Delta lowlands.

These results indicate that during the months of May, June, July, August, September, and October, water was leaving ground water storage and was undoubtedly helping to meet the consumptive use demands. In September, water left storage at the rate of 1,395 second-feet or about 83,500 acre-feet per month.

The second source of information available to make estimates of channel depletion were data from field investigations presently under way on Twitchell Island in the Delta. The same hydrologic equation was used, but in this case seepage only was computed. The change in soil moisture (change in ground water storage) was one of the items for which data were collected at the site. Three rain gage stations were established on the island to measure precipitation; siphons on the island were rated so diversions could be measured; drainage facilities were rated to determine the amount of island drainage returned to the channels; a nuclear probe was used to make random measurements of soil moisture throughout the island;

TABLE 16

ESTIMATED MONTHLY RATES OF CHANGE IN GROUND WATER STORAGE WITHIN DELTA LOWLANDS IN CFS

Month	33 Islands Reported in Ref. 13 (46.4% of Agricultural area)	All Delta Lowlands (100% of Agricultural area)
November	+ 268	+ 578
December	+ 237	+ 511
January	+ 312	+ 672
February	+ 279	+ 601
March	+ 366	+ 789
April	+ 182	+ 392
May	- 312	- 672
June	- 179	- 386
July	- 22	- 47
August	- 129	- 278
September	- 647	-1,394
October	- 300	- 647

and consumptive use (evapotranspiration) was determined using consumptive use factors applied to the acreage of crops as determined by a crop survey of the island. Therefore, the remaining unknown in the hydrologic equation was seepage which could then be solved for.

Available data from the investigation embraced the period December 1, 1959 to July 1, 1960, and the computed seepage rate for this period was 470 acre-feet per month. Expanded over the Delta lowlands on an acreage basis, the seepage would be 840 second-feet, about 200 second-feet higher than the rate determined from the 33-island survey data. It is noted that the normal precipitation for the two periods varied about 6 percent, being 62 percent for the 1954-55 period and 66 percent for the 1959-60 period. Other quantities in the hydrologic equation were similar for the two study periods.

Other indications that monthly consumptive use estimates do not necessarily correspond with channel depletion estimates were obtained by comparing estimated consumptive use in the Delta uplands with measured diversions, less approximated returns. Table 17 shows such a comparison.

TABLE 17

COMPARISON OF ESTIMATED
CONSUMPTIVE USE AND NET DIVERSIONS
IN DELTA UPLANDS

Month	Computed consumptive use, second-feet	Net diversion in second-feet	Difference of consumptive use and net diversion	
			Second-Feet	Percent consumptive use
June	1,340	1,180	160	12
July	1,550	1,210	340	22
August	1,490	1,150	340	23
September	1,130	750	380	34

It is quite evident from Table 17 that the computed consumptive use is much higher than the actual net diversions. If the consumptive use estimates are considered correct, it is therefore possible that the difference between consumptive use and net diversion is the rate of flow from soil moisture which adds to the net diversion to equal the rate of consumptive use. Hence, in the Delta lowlands, using the channel depletion would probably yield a more realistic estimate of the computed Delta outflow. Nevertheless more studies and gathering of data on seepage and changes in ground water storage should be made before channel depletion is substituted for consumptive use in the equation for computing outflow from the Delta.

Net Diversions to Delta Uplands

Net diversions to the Sacramento-San Joaquin Delta uplands are computed as gross channel diversions less return flows from these diversions. Prior to 1955 the Department of Water Resources' publication "Water Supervision Reports" reported on Delta upland diversions from Tom Paine and Cache Sloughs, Old San Joaquin River, and the San Joaquin River only. After that time many additional upland diversions were included in the reports. These additional measurements make a more complete estimate of water use in the Sacramento-San Joaquin Delta and upland areas possible. In this investigation, utilization of this additional data was used in estimating Delta upland diversions.

Table 18 shows the percentage of measured upland diversions used as return flows.

TABLE 18

PERCENTAGE OF MEASURED MONTHLY DELTA UPLAND DIVERSIONS USED AS RETURN FLOWS

January	14	July	3
February	7	August	5
March	4	September	7
April	4	October	16
May	5	November	20
June	4	December	22

These percentages of the diversions used as return flow were based on measurements of return flow published in the 1955 Trial Water Distribution Report on the Sacramento River and Sacramento-San Joaquin Delta (Ref. 12). Measurement of return flows were made for the months of March through October, so percentages were computed for those months, while for the winter months the percentages were estimated.

Subtracting the return flows from the measured diversions gives the net diversions to the Delta uplands.

Net diversions to the Delta uplands were determined for present conditions, with the diversions varying each of the 20 years, depending upon the wetness of the year. For future conditions, upland diversions were not separated from other uses of water in the Delta. The monthly distribution of average net diversions to the Delta uplands for present conditions are shown in Table 19.

TABLE 19

NET PRESENT DIVERSIONS TO DELTA UPLANDS

Month	: Net diversion :1,000 acre-feet
January	0.0
February	0.0
March	12.4
April	37.9
May	44.3
June	58.6
July	70.8
August	59.8
September	37.7
October	17.7
November	1.9
December	0.0
TOTAL	341.1

Municipal and Industrial Use of Water

Water is presently diverted from the channels of the Sacramento-San Joaquin Delta for municipal and industrial uses. One of the municipal users is the City of Antioch which diverts water during winter months, when the quality of water is good, for storage in reservoirs for use in summer months. The approximate diversion in 1958 was 2,250 acre-feet. California Water Service, another diverter of municipal water, diverts from Mallard Slough in months when water quality is good. The quantity of water diverted depends upon the length of time that water of suitable quality is available. The diversion averages about 7,500 acre-feet per year.

Industrial development in the Antioch-Pittsburg complex is fairly intensified, and is expected to become more intense in the future. Most of the industries in the area are high water users. In the future, however, it is probable that water diverted from the channels by industrial users will decrease and other facilities will be used to supply their demands regardless of the operation of State Water Facilities. In any event, there will be about a 15-fold increase in the industrial and municipal use of water in the Delta by 2020. This item is covered extensively in the office report "Delta Water Requirements".

Export of Water from Delta

Presently the U. S. Bureau of Reclamation pumps water out of the Delta for exportation to other areas of need. The canals which deliver the water pumped from the Delta are features of the Central Valley Project and are the Contra Costa and Delta-Mendota Canals. Water is diverted into the Contra Costa Canal from Rock Slough. Diversion began in August

1940. Water is diverted into the Delta-Mendota Canal from Old River. Diversion began in July 1951. Other diversion of water from the Delta include the City of Vallejo which began diverting from Cache Slough in March 1953. The diversion is relatively small, averaging only 10,000 acre-feet per year.

Additional diversions from the Delta will be made in the future. The U. S. Bureau of Reclamation plans to increase the amount of water diverted from their existing facilities and initiate diversion to their proposed East Side Division. The State proposes diversions from the Delta by the North Bay Aqueduct in the Cache Slough area and the California Aqueduct from Italian Slough.

Present and estimated future exportations of water from the Delta are listed in Table 20. Historical records of diversion for Contra Costa and Delta-Mendota Canals, and the Cache Slough Aqueduct, are listed in References 9, 17, and 21.

Outflow of Water from Delta

Previous sections of this chapter discussed the supply of water to the Delta and the utilization of water therein. This section will discuss the outflow from the Delta for natural, historical, present, and future conditions. Because of the complexity of the Delta system, tidal phenomenon, seepage of water from channels into islands, and the use of siphons to divert channel water for surface application to the crops, a precise determination of outflow from the Delta is impossible with existing data. Therefore, Delta outflow must be estimated by combining inflow, precipitation, consumptive use, net diversions, and exportations of water data. Expressed in mathematical form, the outflow equation is:

TABLE 20

ESTIMATED QUANTITIES OF WATER TO BE EXPORTED FROM SACRAMENTO-SAN JOAQUIN DELTA

Thousand of Acre-Feet

Year	Cache Slough	Contra Costa Canal[1,2]	East-Side Division	North and South Bay Aqueducts[3]	Delta-Mendota Canal and San Joaquin-Southern California Aqueduct	Total
1955 (Present)	12	19	0	0	1,181	1,212
1970	19	39	480	99	2,381	3,018
1980	22	55	800	171	4,581	5,629
1990	23	73	1,275	236	5,991	7,598
2000	23	96	1,275	336	8,881	10,611
2020	23	181	1,275	564	9,681	11,724

[1] This exportation is the amount delivered outside the Sacramento-San Joaquin Delta area only and does not include the portion of the total diversion used in the Delta.
[2] Does not allow for integrated operation with Montezuma Aqueduct.
[3] Does not include Montezuma Aqueduct demands.

Outflow = Inflow + Precipitation - Consumptive use in Delta lowlands - Net Diversions to Delta uplands - Exports from Delta.

The above method of computing outflow from the Delta is recognized as a satisfactory method and was employed in these studies.

Natural Outflow from Delta

Natural conditions are defined as those prevailing before any significant agricultural, municipal, or industrial development existed. Natural inflows to the Delta were determined by summing the natural flows at the foothill stations of the Central Valley. These flows were assumed to cross the valley floor and reach the Delta unchanged in magnitude. Subtracting natural monthly consumptive use estimates within the Delta from these inflows and adding precipitation in the Delta determined the outflow from the Delta. Table 21 shows monthly outflows in thousands of acre-feet. Plate 21, "Outflow From Delta Natural Condition", shows the hydrograph of outflow for the 20-year study period.

Historical Outflow from Delta

Outflow for historical conditions for the water years 1921 through 1957 were also computed. Historical monthly outflow is tabulated in Table 22. Data for determining historic outflow were taken from published records, and are included in this report for informational purposes only.

Present Outflow from Delta

To facilitate the estimates of outflow from the Delta for present conditions, use was made of the office report listed as Reference 20.

Determination of present flows in the Delta was necessary to form a basis for predicting surplus flows in the Delta which would be available for export under future conditions of development in the watershed area tributary to the Delta. Present conditions as defined herein, include all water development facilities in the Sacramento and San Joaquin Valleys (excluding Tulare Lake Basin) presently in operation or under construction, with the exception of the Corning Canal unit of the Central Valley Project, and the development of the Sacramento Municipal Utility District on the American River. The proposed South Fork Project of the

TABLE 21

ESTIMATED NATURAL DELTA OUTFLOW

1,000 acre-feet

Water Year	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1921-22	328	512	1,622	1,471	3,996	3,215	4,477	8,057	5,592	1,396	448	299	31,413
23	410	930	3,269	2,516	1,598	1,796	4,242	4,301	2,248	1,046	344	348	23,048
24	426	430	536	666	1,420	708	1,124	1,128	266	133	89	116	7,042
1924-25	349	947	1,297	1,198	6,909	2,718	4,816	4,572	2,290	786	340	266	26,488
26	354	544	829	1,051	4,353	2,021	5,017	2,444	827	290	155	167	18,052
27	295	2,563	2,451	2,922	8,751	4,609	6,106	5,019	3,542	1,089	371	289	38,007
28	383	1,151	1,345	1,685	2,615	7,745	4,552	3,397	1,144	411	219	211	25,458
29	251	588	832	740	1,397	1,487	1,798	2,785	1,509	376	127	146	12,036
1929-30	199	274	3,016	1,955	2,346	3,542	3,093	2,564	1,661	418	183	206	19,462
31	287	458	419	1,021	927	1,385	1,323	1,249	390	81	65	99	7,704
32	250	409	2,505	1,774	2,727	2,942	3,136	4,808	3,390	1,021	272	186	23,420
33	215	306	493	928	704	2,244	2,223	2,706	2,765	509	156	147	13,396
34	269	328	1,446	1,837	2,067	2,215	1,801	1,109	536	138	93	118	11,957
1934-35	242	1,029	983	2,709	1,960	2,980	7,865	5,533	3,284	760	276	194	27,815
36	336	404	618	4,169	7,515	3,501	4,702	4,367	2,641	818	273	218	29,562
37	271	304	614	752	3,635	4,524	4,650	5,891	2,717	751	241	191	24,541
38	342	2,108	6,299	2,440	7,999	10,618	7,532	8,853	5,928	2,092	690	439	55,340
39	596	694	935	953	1,005	2,320	2,595	1,623	626	224	143	221	11,935
1939-40	380	335	794	5,339	8,103	8,206	5,677	4,429	2,038	551	256	260	36,368
41	409	647	5,001	6,093	7,421	6,716	6,438	6,962	3,897	1,618	600	418	46,220
TOTAL	6,592	15,561	35,304	42,219	77,448	75,497	83,167	81,797	47,311	14,508	5,341	4,539	489,284
AVERAGE	330	779	1,765	2,111	3,872	3,775	4,158	4,090	2,366	725	267	227	24,464

TABLE 22

HISTORICAL DELTA OUTFLOW
1,000 Acre-Feet

Water Year	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1921-22	433	548	1,560	1,609	4,145	3,326	3,871	5,205	3,772	782	72	222	25,545
23	511	932	3,236	2,607	1,639	1,504	3,522	2,526	1,338	408	37	264	18,524
24	558	498	602	739	1,423	595	588	240	- 50	-169	-149	12	4,887
25	337	806	1,205	1,125	6,727	2,338	4,181	3,274	1,366	220	- 16	173	21,736
26	444	611	904	1,085	4,449	1,672	3,740	1,245	210	90	-103	142	14,309
27	421	2,278	2,334	2,801	8,728	4,512	5,377	3,255	2,081	360	54	223	32,424
28	528	1,478	1,394	1,731	2,510	7,136	3,933	1,907	444	58	- 27	190	21,282
29	396	731	875	897	1,475	1,301	1,123	1,108	566	- 26	- 52	155	8,549
30	334	379	2,360	2,140	1,884	3,500	2,073	1,333	574	2	- 40	234	14,773
1930-31	466	573	590	1,046	910	1,061	383	159	- 21	-243	-215	18	4,727
32	209	420	1,673	2,144	2,404	2,175	1,955	2,837	1,993	393	- 44	87	16,246
33	257	361	617	967	933	1,649	1,354	1,206	1,116	3	-117	92	8,438
34	334	466	1,142	2,025	1,718	1,680	949	323	82	-149	-154	63	8,479
35	238	880	826	2,859	1,668	3,059	6,879	3,973	2,095	229	- 1	172	22,877
36	480	539	758	3,921	7,010	3,956	3,618	2,809	1,712	242	4	221	25,262
37	378	435	688	896	3,516	4,963	4,108	3,625	1,796	211	- 66	139	20,689
38	491	2,098	5,457	2,637	8,924	11,661	7,252	6,834	4,792	1,365	297	351	52,159
39	653	853	1,133	1,086	1,115	1,662	1,097	463	45	-135	-131	157	7,998
40	349	379	718	4,208	5,881	8,540	7,270	2,792	1,242	107	- 5	265	31,746
1940-41	452	728	4,030	7,302	7,662	7,802	6,713	4,934	2,760	891	168	246	43,688
42	511	741	3,865	5,570	8,693	3,049	5,132	4,311	3,327	841	109	300	36,449
43	564	1,033	1,950	5,580	4,447	7,005	4,345	2,740	1,559	205	26	214	29,668
44	529	648	798	1,001	1,966	2,207	1,163	1,525	600	18	- 14	207	10,648
45	384	1,092	1,504	1,291	4,482	2,495	2,150	2,442	1,465	407	253	414	18,379
46	752	1,228	4,672	4,945	1,768	2,039	2,277	2,393	914	251	218	407	21,864
47	574	988	1,359	986	1,573	2,152	1,443	575	370	71	100	292	10,483
48	631	790	663	1,560	797	1,341	3,522	3,669	2,523	420	276	484	16,676
49	638	731	988	898	968	3,755	1,970	1,599	558	141	185	346	12,777
50	406	605	643	1,913	3,028	2,204	2,680	2,101	1,255	249	191	402	15,677
1950-51	670	4,304	8,183	4,862	5,054	3,297	1,747	2,043	645	264	275	411	31,755
52	595	974	3,049	6,628	5,988	5,366	6,115	6,406	3,923	1,076	387	555	41,062
53	597	804	2,532	7,135	2,139	1,662	1,770	2,179	1,960	321	140	536	21,775
54	631	929	1,021	1,984	4,008	3,637	3,370	1,715	330	34	135	398	18,192
1955	547	1,013	1,839	1,870	1,041	809	734	1,109	397	90	14	308	9,851
56	360	645	7,888	11,718	5.900	3,967	2,346	3,601	2,107	513	353	619	40,017
57	837	989	944	1,077	1,491	3,960	1,172	2,031	901	118	144	501	14,1[illegible]
TOTAL	17,495	33,507	[illegible],000	102,823	128,064	123,036	111,922	90.487	50,747	9,478	2,356	9,860	153,7[illegible]

Oroville-Wyandotte Irrigation District on the Feather River was considered to be in operation. Demands to be met by existing projects were taken as the largest measured annual diversion during the five-year period 1950-55 on a monthly schedule representing the average of monthly diversions during those five years.

The Central Valley Project was operated to meet mandatory demands, namely diversions along the Sacramento River; navigation requirements; "minimum" salinity repulsion "of 3,300 second-feet"; consumptive use requirements in the Delta; present export requirements from the Delta; and necessary fishery releases. In addition, sufficient power was generated to meet project requirements and power contracts. Shasta and Folsom Reservoirs were operated in accordance with existing flood control operational criteria.

Operation of present water development facilities over the selected historical water supply period of 20 years provides a basis for determination of surplus flows that would waste to San Francisco Bay after the foregoing requirements are met. These surplus flows may result from uncontrolled inflow, project spill, or project releases in excess of mandatory demands listed in the preceding paragraph. Monthly outflows from the Delta for the 20-year study period under present conditions of development, with a minimum outflow regulation of 3,300 second-feet, are shown in Table 23. The hydrograph of outflow is shown on Sheet 1 of Plate 22, "Outflow from Delta--Present Conditions of Development".

The outflows presented in Table 23 and on Sheet 1 of Plate 22 differ slightly from the outflows shown for present conditions in Reference 20. These differences arise from the use of revised data for Delta upland diversions and the use of actual precipitation data in place of mean monthly precipitation.

TABLE 23

ESTIMATED PRESENT DELTA OUTFLOW WITH 3,300 SECOND FEET MINIMUM

1,000 acre-feet

Water Year	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1921-22	533	666	1,311	1,218	3,242	2,473	2,344	3,605	2,481	348	203	443	13,867
23	717	1,123	3,001	2,547	1,354	1,024	2,389	1,556	733	203	203	396	15,246
24	480	555	887	765	1,118	474	358	203	196	203	203	294	5,736
25	427	572	934	778	5,252	1,625	2,134	1,806	590	203	203	358	14,882
26	394	522	851	928	4,520	1,094	2,095	615	196	203	203	314	11,935
27	435	1,398	2,001	2,385	8,586	3,375	3,630	2,289	1,211	203	203	418	26,134
28	610	1,488	1,236	1,668	2,457	6,372	2,844	1,397	196	203	203	259	18,933
29	367	590	896	778	1,278	710	481	384	282	203	203	246	6,418
30	350	433	1,822	1,590	1,812	2,705	1,251	778	255	203	203	282	11,684
1930-31	423	505	533	783	681	657	257	203	196	203	203	279	4,923
32	383	499	1,256	1,568	1,720	1,210	1,038	1,827	1,401	203	203	269	11,577
33	301	481	863	786	706	672	584	511	649	203	203	205	6,164
34	359	457	883	1,344	1,382	1,032	477	203	196	203	203	246	6,935
35	351	665	832	1,999	1,213	2,136	5,339	3,057	1,305	203	203	260	17,563
36	417	477	837	3,622	7,017	3,011	2,239	2,026	1,232	203	203	272	21,556
37	353	415	847	725	2,795	4,061	3,067	2,792	1,106	203	203	237	16,804
38	386	2,296	5,349	1,995	8,424	9,698	5,931	5,962	3,342	606	203	382	44,574
39	958	828	1,121	958	1,039	1,387	588	332	196	203	203	271	8,084
40	412	450	506	3,369	5,408	6,848	5,727	2,071	767	203	203	336	26,300
1940-41	432	583	4,389	6,923	7,169	5,962	5,413	3,944	1,629	304	203	312	37,263

Monthly outflow with a minimum 3,300 second-foot release was further modified to develop monthly outflow with a minimum 1,500 second-foot release. This was accomplished by a detailed review of the mandatory releases for navigation, fish releases, and other requirements for water allowed in the basic study. In instances where releases had been specifically made to maintain the 3,300 cfs minimum outflow, the reduction to 1,500 cfs was made. In some instances, however, the reductions could not be made if retention of this water in storage violated flood control reservations in either Folsom or the Shasta Reservoirs. In cases where releases could be stored the difference between 1,500 and 3,300 cfs was placed in storage. New reservoir storage data were developed on a monthly basis for the entire study period. These adjusted storages were never allowed to exceed the flood control reservations. Whenever storage encroached upon the critical flood control storage reservation, water was released from the reservoir in such quantity as to conform with the necessary flood reservations. The resulting monthly outflow, based on the 1,500 second-feet minimum salinity control outflow, is tabulated in Table 24. Sheet 2 of Plate 22 shows the hydrograph of outflow from the Delta with a 1,500 second-feet minimum salinity release.

Future Outflows from Delta

Future outflows from the Delta were developed from operation studies determining present outflows from the Delta. The operation studies for present conditions with 3,300 second-flow minimum outflow were modified to reflect a lower minimum outflow, generally of 1,000 second-feet. Flow available for diversion through the Delta-Mendota Canal and the proposed state canal to San Luis Reservoir were then

TABLE 24

ESTIMATED PRESENT DELTA OUTFLOW WITH 1.500 SECOND FEET MINIMUM
1,000 acre-feet

Water Year	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1921-22	533	666	1,311	1,218	3,242	2,473	2,344	3,605	2,481	348	98	443	18,762
23	822	1,123	3,001	2,547	1,354	1,024	2,389	1,556	733	92	92	396	15,129
24	503	555	887	765	1,170	495	358	162	89	92	98	294	5,468
25	427	572	970	837	5,647	1,625	2,134	1,806	590	92	92	358	15,150
26	394	522	851	928	4,742	1,094	2,095	615	91	92	92	314	11,830
27	435	1,473	2,089	2,497	8,638	3,375	3,630	2,289	1,211	175	92	418	26,322
28	614	1,623	1,236	1,668	2,457	6,372	2,844	1,397	196	92	92	259	18,850
29	367	590	896	778	1,278	710	481	601	287	92	92	246	6,418
1929-30	350	433	1,822	1,721	1,898	2,710	1,251	778	255	92	92	282	11,684
31	423	505	533	783	681	657	257	180	89	92	92	279	4,571
32	383	499	1,357	1,730	1,970	1,271	1,038	1,827	1,401	145	92	269	11,982
33	301	481	863	786	706	672	584	680	649	92	92	160	6,066
34	359	457	883	1,412	1,504	1,096	477	190	89	92	92	246	6,897
35	351	665	832	1,999	1,301	2,284	5,458	3,057	1,305	94	92	252	17,690
36	417	477	837	3,850	7,017	3,011	2,239	2,026	1,232	92	92	272	21,562
37	353	415	847	725	3,017	4,061	3,067	2,792	1,106	128	92	231	16,834
38	386	2,369	5,468	1,995	8,424	9,698	5,931	5,962	3,342	606	131	382	44,694
39	1,030	828	1,121	958	1,039	1,387	588	332	90	92	92	271	7,828
1939-40	412	450	506	3,679	5,426	6,848	5,727	2,071	767	92	92	336	26,406
41	432	583	4,611	6,923	7,169	5,962	5,413	3,944	1,629	304	95	312	37,377
TOTAL	9,292	15,286	30,921	37,799	68,680	56,825	48,305	35,870	17,632	2,996	1,894	6,020	331,520
Mean	465	764	1,546	1,890	3,434	2,841	2,415	1,793	882	150	95	301	16,576

developed from the information on surplus flows. Under conditions of future development the surplus flows were reduced in quantity by the estimated increased upstream uses. The time of occurrence of the upstream uses was adjusted to conform with future regulatory works expected within the drainage basin. As previously discussed, the future requirements for water within the basin were determined for several future conditions of development.

Rather than estimating the effect of a number of specific reservoirs to regulate the surplus flows to meet anticipated demands, a single hypothetical reservoir was utilized for the purpose. For each condition of development, storage was assumed to be available in the amount just sufficient to reregulate surplus flows in the Delta to meet monthly requirements of increased upstream use. Spills from the hypothetical reservoir for each condition of development, plus the difference between 3,300 cfs minimum release and a lower minimum release for future conditions, made up the surplus flows in the Delta which could be utilized for meeting export requirements. The export requirements included diversions to the East Side Division of the Central Valley Project, the North and South Bay Aqueducts, and the Federal and State San Luis Projects. Operation of Oroville Reservoir was also included in the determination of surplus flows in the Delta.

Operation studies by machine computation, utilizing surplus flows in the Delta as the available supply, were run to determine the remaining flows in the Delta after export demands were met. The remaining flows were added to the minimum outflow to give the total Delta outflow. Operation studies are made for two general categories of future development; namely, 1970 and 1980, and 1990 to 2020 when importation of north coast water would be necessary. Future outflow from the Delta is discussed under these two categories.

1970 and 1980 Conditions of Development. Surplus flows in the Delta in 1970 and 1980 were sufficient to meet demands for pumping to San Luis Reservoir so that importation of water from streams on the north coast was not needed.

In 1970, Delta water facilities were assumed to be in an interim stage of construction, so an outflow of 1,500 second-feet was considered necessary to operate the facilities. This, incidentally, is also the outflow from the Delta that the Bureau of Reclamation claims is necessary to operate the Central Valley Project. Consequently, in the Delta in 1970 an outflow from the Delta of 1,500 second-feet was used to determine surplus flow.

Also considered constructed and in operation was Oroville Reservoir. The outflow from the Delta after export demands were met in 1970 was computed, and a tabulation of such outflow is filed in the back-up data. The 1980 surplus flows in the Delta were routed through San Luis Reservoir in a manner similar to that for 1970. A tabulation of these data are not included in this report but are in the back-up data.

1990 to 2020 Conditions of Development. Inasmuch as demands at these conditions of development could not be met from surplus flows in the Delta alone, importation of water from the north coast was necessary, as well as invocation of the Bureau of Reclamation-State of California, Department of Water Resources (USBR-DWR) agreement of May 16, 1960.

The effect of the USBR-DWR agreement on the operation studies are discussed first. At these future conditions of development the estimated requirements of upstream water users in the Central Valley were such that additional water was needed to meet demands.

The agreement between the USBR and the DWR provides for coordination of operation of facilities of each agency. In the event that water supplies are insufficient to meet demands, the two agencies will share deficiencies in proportion to the total requirements of each agency. Requirements of the Bureau of Reclamation are estimated at 9.5 million acre-feet annually, including the federal portion of San Luis Reservoir, and requirements of the State are estimated at 4 million acre-feet, for a total requirement of 13.5 million acre-feet.

The Bureau of Reclamation and the department have both estimated combined project yields of water for all projects in the Central Valley with yields estimated by the department lower than those estimated by the Bureau of Reclamation. The department estimates of yield considered greater upstream development and use of water than those of the bureau, resulting in smaller surplus flows in the Delta. If, after meeting demands upstream from the Delta and in the Delta lowlands there are insufficient supplies to meet demands on San Luis Reservoir, North and South Bay Aqueducts, the bureau will reduce its deliveries of water by 70 percent of the amount of the deficiency.

The estimated monthly surplus flows in the Delta were further modified to eliminate apparent inconsistencies in the resulting outflows from the Delta. These modifications were applicable when outflows from the Delta in summer months were greater than the minimum outflow regulation and resulted in waste of water at a time when maximum conservation was required. In those instances where the increased surpluses resulted from the agreement, the quantity of water allocated to the State by the agreement was reduced by an amount so that the waste of water was minimized. The estimated surplus flows available for the State were also modified in months of flood and at other times in the wet season. It appeared inconsistent with the USBR-DWR agreement to modify surplus flows available in the Delta in a month or period of abundant supply. The modifications to the estimated surpluses were necessitated by the fact that independent and separate studies were used to reflect combined operation of state, federal, and local facilities envisioned in the future.

The surplus flows as modified by the USBR-DWR agreement were then examined to determine the quantities of import water which would be required to meet the demands at the condition of development being studied. A monthly schedule of import water was selected from studies currently in progress by the department. The import water would originate from water development projects envisioned on north coastal streams. Water so developed would be delivered on a power schedule to the Sacramento River Basin into the proposed Glenn Reservoir. The site of the proposed reservoir is on Stony Creek, about 50 miles north of Sacramento. The reregulation of flow in this reservoir was made in a manner to satisfy both water supply and power requirements. The modified surplus flows in the Delta plus the reregulated flows from the north coast were routed through the Delta to San Luis Reservoir. From these studies the outflow from the Delta was determined.

Examination of the Delta outflow showed that the reregulation of import supplies in certain months appeared unrealistic for coordinated operation of state and federal regulatory works. In order to realistically represent coordinated operation, suitable adjustments were made to the outflow from the Delta in summer months. These adjustments eliminated the possibility of imported water being released from the proposed Glenn Reservoir during critical dry periods and wasted to the sea when such water would be needed for beneficial use. Similar corrections could have been applied in certain high flow months, but since corrections would not significantly effect the quality of water in the Delta channels in these months, such corrections were not made.

The described modifications to the Delta outflow, together with the modifications required by application of the agreement between the USBR-DWR changed the results of the operation studies in such a manner as to more nearly approximate the expected operation under joint state and federal cooperation. The modifications were based on the theory that it is inconceivable in times of short water supplies and high demands that operation of a major water facility will waste vitally needed water. Although the adjustments may appear to be arbitrary it is believed they are prudent engineering judgments.

Tables 25 and 26 list the outflow from the Delta for 1990 and 2020 conditions of development. Plate 23, "Outflow From Delta, 1990 Condition of Development", and Plate 24, "Outflow From Delta, 2020 Condition of Development", show the hydrographs of outflow for these two future conditions of development. For these two conditions the monthly outflow is on a calendar year rather than a water year.

The importation of water from streams on the north coast to the Sacramento River Basin was staged to meet the estimated demands for water at all conditions of development. The general criteria used to

TABLE 25

ESTIMATED 1990 DELTA OUTFLOW WITH 1,000 SECOND FEET MINIMUM

1,000 acre-feet

Water Year	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Total
1922	995	2,983	2,181	1,149	2,511	1,393	61	61	60	61	60	1,813	13,328
1923	2,150	1,103	476	1,430	370	60	61	61	60	61	60	61	5,953
1924	61	56	61	60	61	60	61	61	60	61	60	61	723
1925	61	2,166	815	1,100	672	60	61	61	60	61	60	61	5,238
1926	61	2,745	377	947	61	60	61	61	60	61	60	61	4,615
1927	1,588	7,740	2,719	2,229	1,053	119	61	61	60	61	60	137	15,888
1928	1,419	2,067	5,876	1,725	61	60	61	61	60	61	60	61	11,572
1929	61	56	61	60	61	60	61	61	60	61	60	61	723
1930	61	786	1,757	146	61	60	61	61	60	61	60	61	3,235
1931	61	56	61	60	61	60	61	61	60	61	60	61	723
1932	61	56	61	60	61	60	61	61	60	61	60	61	723
1933	61	56	61	60	61	60	61	61	60	61	60	61	723
1934	61	56	61	60	61	60	61	61	60	61	60	61	723
1935	61	56	1,239	3,516	1,376	60	61	61	60	61	60	61	6,672
1936	1,506	6,087	2,098	806	430	60	61	61	60	61	60	61	11,351
1937	61	1,093	3,096	2,107	1,324	60	61	61	60	61	60	4,006	12,050
1938	1,570	8,022	9,218	5,055	4,864	2,077	61	61	60	61	60	157	31,266
1939	712	778	861	60	61	60	61	61	60	61	60	61	2,896
1940	61	3,887	6,067	4,426	743	60	61	61	60	61	60	1,947	17,494
1941	5,900	6,742	5,557	4,416	2,737	353	61	61	60	61	60	61	26,069
TOTAL	16,572	46,591	42,703	29,472	16,690	4,902	1,220	1,220	1,200	1,220	1,200	8,975	171,965
Average	829	2,329	2,135	1,474	834	245	61	61	60	61	60	449	8,598

TABLE 26

ESTIMATED 2020 DELTA OUTFLOW WITH 1,000 SECOND FEET MINIMUM

1,000 acre-feet

Water Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOTAL
1922	61	2,829	2,033	1,024	2,306	1,309	61	61	60	61	60	595	10,460
1923	1,818	658	203	1,276	192	116	61	61	60	61	60	61	4,627
1924	61	56	61	60	61	60	61	61	60	61	60	61	723
1925	61	56	61	486	325	204	61	61	60	61	60	61	1,557
1926	61	500	61	580	61	60	61	61	60	61	60	61	1,687
1927	61	7,334	2,327	1,985	826	204	61	61	60	61	60	61	13,101
1928	61	1,344	5,370	1,436	61	60	61	61	60	61	60	61	8,696
1929	61	56	61	60	61	60	61	61	60	61	60	61	723
1930	61	56	61	60	61	60	61	61	60	61	60	61	723
1931	61	56	61	60	61	60	61	61	60	61	60	61	723
1932	61	56	61	60	61	60	61	61	60	61	60	61	723
1933	61	56	61	60	61	60	61	61	60	61	60	61	723
1934	61	56	61	60	61	60	61	61	60	61	60	61	723
1935	61	56	61	60	61	60	61	61	60	61	60	61	723
1936	61	4,127	1,926	675	387	204	61	61	60	61	60	61	7,744
1937	61	56	2,825	1,575	1,098	71	61	61	60	61	60	3,062	9,051
1938	1,310	7,658	8,936	4,857	4,172	1,965	61	61	60	61	60	61	29,262
1939	61	56	61	60	61	60	61	61	60	61	60	61	723
1940	61	1,947	5,702	3,930	338	209	61	61	60	61	60	61	12,551
1941	5,884	6,348	5,265	4,241	2,511	438	61	61	60	61	60	61	25,051
TOTAL	10,049	33,361	35,258	22,605	12,826	5,380	1,220	1,220	1200	1,220	1,200	4,755	130,294
Average	503	1,668	1,763	1,130	641	269	61	61	60	61	60	238	6,515

determine when water should be imported was that a total deficiency greater than 100 percent of the annual requirements averaged over the critical dry period of 1928 through 1935 would not be allowed. The deficiency was applied only to agricultural water supplies and not to municipal and industrial water supplies. The amount of water imported at various levels of development and the probable source of such supplies are tabulated in Table 27.

TABLE 27

ESTIMATED QUANTITIES OF WATER IMPORTED TO THE CENTRAL VALLEY DRAINAGE BASIN FROM NORTH COAST STREAMS

Project unit	Seasonal import in acre-feet	Date required
Middle Fork Eel River	Variable averaging 597,000	1990
Trinity No. 1	495,000	2000
Trinity No. 2	1,298,000	2000
Mad-Van Duzen	371,000	2020
Klamath No. 1	2,629,000	2020

Staging of Projects. In all of the future operation studies it was assumed that water demands would be met. This meant that projects to develop certain quantities of water must be completed at the time that the preceding units can no longer meet the demands. As each new project is brought into operation there would be an interim period in which the supply of water would be in excess of the needs. It appears possible, under future operations, that if a severe dry period develops, it might be at a time when excess supplies are available. In that event, the deficiency of water would not be as serious as anticipated. On the other hand, the staging of new water development projects must not be allowed to fall behind the demands for water. If such happens, then the length of time that deficiencies may be endured could be more frequent.

CHAPTER V. OPERATION OF DELTA WATER FACILITIES

The most economical transport of surplus water from Northern California to areas of water deficiency south of the Delta, dictates that works must be constructed within the Delta. These facilities must be able to: (1) transfer fresh water across the Delta without degradation from sea water; (2) provide an adequate supply of good quality water to the Delta; and (3) serve other multipurpose functions, such as flood control, seepage reduction, and recreational and transportation improvements which are economically justified and desired by local interests. Studies of four alternative facilities were made to determine the most economical plan for solving the above requirements.

These four plans have been presented in Bulletin No. 76 to the local people as a means of obtaining the local viewpoint in project formulation. After each of the plans is evaluated in terms of costs and benefits received, a logical and intelligent selection of a plan best suited to the local needs can be made. The four plans presented for consideration are: (1) Comprehensive Delta Water Project, (2) Typical Alternative Delta Water Project, (3) Single Purpose Delta Water Project, and (4) Chipps Island Barrier Project.

Comprehensive Delta Water Project

The Comprehensive Delta Water Project would be a multipurpose project incorporating many of the concepts envisioned in the former Biemond Plan (Reference 2). Fresh waters entering the Delta for export would be restricted to an enlarged natural channel crossing the Delta; flood waters would be confined to specific channels; water for use in the Delta would be provided in channels generally separated from tidal waters. Plate 25, "Comprehensive Delta Water Project", shows the many features of the project.

Details of this project include control structures located on the Sacramento River near Ryde; on Steamboat Slough downstream from the junction of the two sloughs adjacent to Sutter Island; on Holland Cut; the slough immediately south of Franks Tract; and on Paradise Cut, the slough south of Stewart Tract. There is also a ship lock and fishway at the control structure near Ryde, and a Cross-Delta Canal headwork, including a fish screen, at Walnut Grove. The master levee system isolates the Cross-Delta Canal, except at its intersection with the San Joaquin River, and in conjunction with existing project levees, separates specific channels from tidal influence. As a result of these levees separate island-groups are formed. By enclosing these island-groups, fewer miles of levees must be maintained for flood protection to the Delta. Closures on the smaller sloughs enable the exclusion of flood and tidal waters, and provide a means of isolating water supply channels for the Delta. The Bear Creek Diversion would divert flood waters from Bear Creek into Delta channels confined by master levees. Features to provide good quality water to the Delta are also depicted on Plate 25. The operation of these features are described in the companion appendix reports "Delta Water Requirements", and "Plans, Designs, and Cost Estimates". In general, the channels severed from tidal and flood waters by the master levees would serve as supply channels for irrigation water. Water levels in these interior channels would be maintained at levels about five feet lower than existing mean water levels or at existing low tide levels. In the western portion of the Delta, distribution canals along the toe of the levees would provide a means of serving water to areas in which the adjacent exterior channels contain water too saline for use.

In the event that excessive releases of high quality water are required to protect the quality of water crossing the Delta, or that additional degradation from the San Joaquin River occurs, additional works may be economically justified for construction as part of the Comprehensive Delta Water Project These features are presently considered as a second stage of the project. Present economic studies as well as the salinity-outflow relationship are not sufficiently refined to make final determination of when and if the second-stage features would be required.

Included among the second-stage facilities are: (1) a siphon under the San Joaquin River for the Cross Delta Canal, a gated control structure, fishway, and small craft lock at the southeastern tip of Venice Island; (2) a barge lock at the control structure adjacent to Holland Tract; (3) control structures on three sloughs in the Yolo Bypass area; (4) siphons under three waterways in the Yolo Bypass area, to isolate the water supply for the proposed North Bay Aqueduct from tidal waters; and (5) a control structure at the junction of the San Joaquin and Old Rivers between Upper Roberts Island and Stewart Tract.

Construction of second-stage features may enable the conservation of approximately 250 second-feet of salinity control flows. Even though saline waters would invade the Delta channels further upstream as a result of less outflow from the Delta the fresh water channels would be isolated from the influences of tidal waters.

Summer Operation

In the summer months, or other times when the Comprehensive Delta Water Project would be operated for water supply and water transfer, most of the water entering the Delta from the Sacramento River would be diverted into the Cross-Delta Canal. The remaining flows would be released through the control structure on the Sacramento River for supplying demands along the river in the Cache Slough and Yolo Bypass areas, for the North Bay Aqueduct, and for salinity control. The gated control structure on Steamboat Slough would be closed. All of the controlled releases would be made from the structure on the Sacramento River at Ryde. The barge lock and fishway structure at Ryde would of course be operative, and water utilized in their operation would supply part of the demands below the structures.

The South Fork of the Mokelumne River and the sloughs between Boulden Island and Terminous Tract, and between Venice Island and Empire Tract would serve as the Cross-Delta Canal in the northern part of the Delta. These channels would be enlarged by dredging. The existing headworks of the USBR's Delta Cross Channel would also be enlarged so that greater flows than at present could be diverted from the Sacramento River into the Cross-Delta Canal. With these enlargements, future Delta and export demands of about 20,000 second-feet, could be transferred across the Delta without increasing the Sacramento River stage at Walnut Grove above the present high water elevation of approximately 4.5 feet.

Water being transferred across the Delta for export would mix with tidal water in the San Joaquin River near Venice Island. It would then continue southward through the southern portion of the Cross-Delta Canal which would consist of Columbia Cut between Medford Island and

McDonald Tract; Connection Slough between Mandeville and Bacon Islands; and Old River to Italian Slough, northwest of Clifton Court Tract. A schematic diagram of the distribution of design summer flows through the Delta for the Comprehensive Delta Water Project is shown on Plate 26, "Comprehensive Delta Water Project, Summer Flow Distribution". The rate of flow in reaches of the Delta is indicated by figures over the arrows showing direction of flow. Proceeding across the Delta, the rates of flow in succeeding reaches decrease because a rate of flow for diversions to satisfy consumptive use in the upper reach is deducted. A total consumptive use in the Delta of 5,100 second-feet was used in determining the distribution of flows and the export demands are for ultimate design capacities of the export facilities.

Winter Operation

In winter months or times of flood flows the gates of the control structures would be open and the headworks of the Cross-Delta Canal would normally be closed. Flood flows in the Sacramento River would pass the control structures and proceed downstream into Suisun Bay. Mokelumne River flood flows would pass down the Cross-Delta Canal and enter the San Joaquin River at Venice Island. San Joaquin River flood flows would divide between Paradise Cut; Old River, which is located between Upper Roberts Island and Stewart Tract; and the San Joaquin River; and later recombine and enter into Suisun Bay.

A schematic diagram of the distribution of design flood flows through the Delta under operation of the Comprehensive Delta Water Project is shown on Plate 27, "Comprehensive Delta Water Project, Winter Flow Distribution". The magnitude of design flood flows entering the Delta is based on existing project floods and/or future conditions of upstream development in the river basins. To obtain the maximum flows in a reach the consumptive use was assumed to be met from precipitation on the Delta, and export of water from the Delta was assumed zero.

Tidal Conditions

With construction of the master levee system and closures on the many sloughs in the Delta for the Comprehensive Delta Water Project, about 15,500 acres of channel surface area would be removed from the influence of tidal movements. In Bulletin No. 60, the assumption was made that the elimination of this water surface would not change tidal conditions throughout the Delta and Bay system, and that the tidal prism would be reduced in proportion to the reduction of channel water surface area removed from tidal influence. To determine the validity of this assumption, studies were undertaken on an electronic analog model of the Bay and Delta. These studies of tidal conditions in the Delta were conducted by the University of California at Berkeley under a standard agreement between the university and the department. The analog model was also used to determine the effect of the Chipps Island Barrier Project on tides. The results of these studies were published in Report No. 2, "An Electric Analog Model Study of Tides in the Delta Region of California", (Reference 40).

The Delta portion of the analog model was laid out on a large tee shaped board on which standard 1:24,000 USGS topographical maps of the Delta were placed. The San Francisco Bay portion of the model was placed on an aluminum chasis without regard to geometric correctness. Reaches of the channels were represented by discrete electric plug-in units in which resistance represented channel friction; inductance represented inertia of flow; and capacitance represented water surface area. Electrical voltage represented water elevation or head.

To make measurements of flow and tidal amplitudes on the analog, electrical instruments were designed to be inserted into the computer circuitry by means of jacks. Measured tidal amplitudes and tidal currents were displayed on the screen of an oscilloscope. Before measurements of tidal conditions for project conditions were made, the analog was verified by means of an input of data collected in the field. The comparison of tidal amplitudes and phases as measured on the model with those measured in the prototype is shown on Plate 28, "Comparison of Prototype Tidal Phases and Amplitudes with Analog Model Tidal Phases and Amplitudes".

Plate 28 shows the comparison for both the Sacramento and San Joaquin Rivers. The prototype data were collected as shown in Reference 32. The locations of tide gages from which the data were obtained are noted along the ordinate, with the downstream station at the top of the plate and the upstream station at the bottom. The amplitude of the tide (in feet) from higher low tide and the phase of the tide in hundreds of minutes after occurrence at the Golden Gate, is shown along the abscissa. The circles represent the data from the prototype and the triangles represent data from the analog. On the Sacramento River the downstream station was Point San Pablo and the upstream station was Sacramento. On the San Joaquin River the downstream station was Collinsville and the upstream station was Mossdale. It is seen that agreement between the prototype and analog data for existing conditions is very close. Therefore measurements of tidal conditions on the analog for project conditions would be rational.

Analog studies were conducted at the time when facilities for the Delta were known as the Biemond Plan. In fact, in the analog report submitted by the University of California to the department, results of measurements were reported on the Junction Point Barrier Plan, a plan in which barriers were conceived on both Steamboat Slough and the Sacramento River immediately upstream from their confluence with Cache Slough and the modified Biemond Plan which is essentially identical to the Comprehensive Delta Water Project. The essential difference between the two plans is that the master levee around Bradford Island, Webb Tract, and Mandeville Island, has been eliminated and the siphon under the San Joaquin River has not been included in the Comprehensive Delta Water Project. However, these differences should not have changed tidal measurements made for the Comprehensive Delta Water Project from those made for the modified Biemond Plan. Tidal amplitudes at selected locations in the Bay and Delta resulting from the modified Biemond Plan, as measured on the analog, are shown in Table 28.

TABLE 28

EFFECTS OF MODIFIED BIEMOND PLAN
ON A TYPICAL SPRING TIDE[1]
(No master levee system)

Location	Tidal Amplitude, in feet	
	No Control Structures	With Control Structures
Selby	6.0	6.0
Chipps Island	4.6	4.7
Rio Vista	4.7	5.0
Ryde	3.4	5.2
Confluence, Steamboat and Sutter Sloughs	4.1	5.3

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[1] Features of modified Biemond Plan are similar to those of the Comprehensive Delta Water Project, so tidal effects of each would be the same.

Measurements on the analog computer indicated that tidal amplitudes would be similar regardless of the construction of a master levee system and closures on all sloughs. Table 29 shows the effects of the modified Biemond Plan on the amplitudes of an extreme spring tide at Ryde with and without control structures and a master levee system.

TABLE 29

EFFECTS OF MODIFIED BIEMOND PLAN
ON AN EXTREME SPRING TIDE[1]
SACRAMENTO RIVER DELTA

Location	Tidal amplitude, in feet above lower low tide			
			With control structures	
	No control structures		No master levee system	With master levee system
Golden Gate	Higher high	8.5	Same	Same
	High low	3.0	Same	Same
	Low high	6.3	Same	Same
Ryde	Higher high	5.2	6.8	6.9
	High low	2.0	2.5	2.8
	Low high	3.7	5.4	6.0
Height of mean tidal plane at Ryde above that at Golden Gate			1.2	1.0

[1] Features of modified Biemond Plan are similar to those of the Comprehensive Delta Water Project, so tidal conditions in each should be the same.

Tidal amplitudes shown in Table 29 are actually the height in feet of each of the tidal phases above lower low tide. The datum elevation of the lower low tide was not determined. It can be seen, then, that with barriers the tidal amplitudes at Ryde on the Sacramento River with and without the master levee system are about the same. At locations along the San Joaquin River, however, the master levee system and closures of many sloughs does have an effect on the tidal amplitudes.

For a typical spring tide, the effects of the master levee system on the tidal amplitudes at locations along the San Joaquin River are shown in Table 30.

TABLE 30

EFFECTS OF MASTER LEVEE SYSTEM
ON A TYPICAL SPRING TIDE
SAN JOAQUIN RIVER DELTA

Location	Tidal amplitudes, in feet	
	Without master levee system	With master levee system
Collinsville	4.5	4.7
Antioch Bridge	4.1	4.7
Mouth, False River	3.6	4.6
San Andreas	3.5	4.6
Mouth, Middle River	3.6	4.8
Venice Island	3.8	4.9
Rindge pump	4.0	5.2
Calaveras River	4.0	5.2
Brandt Bridge	3.3	3.8

From Table 28, 29, and 30, it is apparent that construction of the Comprehensive Delta Water Project will affect tidal conditions in the Sacramento-San Joaquin Delta. For a typical spring tide at the Golden Gate, measurements on the electronic analog model indicate that (1) the tidal amplitude would be increased about 1.8 feet on the Sacramento River downstream from the control structure at Ryde; (2) on Steamboat Slough downstream from the control structure the amplitude would be increased about 1.2 feet; and (3) along the San Joaquin River the amplitude would be increased about one foot. Just how the increased amplitudes would affect the height of low and high waters of the tidal phases was not determined, but it was assumed the increased amplitude would be about equally divided between lowering the low waters and raising the high waters.

The findings on the analog of tidal amplitude changes in the Delta by construction of barrier and master levee systems led to the question of how these changes affected the tidal prism in the Delta. Computations were made of the tidal prism in the Delta above Chipps Island for existing tidal conditions and for tidal conditions as indicated by measurements on the analog with construction of the Comprehensive Delta Water Project. The tidal prism for the two tidal conditions revealed less than a four percent difference at various locations in the Delta. In other words, the increased tidal amplitude on the channels remaining tidal under the Comprehensive Delta Water Project, when reflected in tidal prism computations, compensate for smaller tidal amplitudes acting on all water surface areas without the project. Inasmuch as the tidal prism in the Delta, as computed for Comprehensive Delta Water Project conditions, is the same as for existing conditions, it is expected that outflows to control salinity for both conditions would also be about the same.

Outflow to Operate Project

In order to conserve the maximum quantity of water from salinity control flows, the minimum outflow to operate the Comprehensive Delta Water Project had to be determined. This was done by finding the minimum outflow to keep the incursion of saline water at two key locations in the Delta at concentrations which would not seriously degrade the water for export or supply within the Delta. The two key locations were (1) the junction of Cache and Steamboat Sloughs with the Sacramento River, about two miles upstream from Rio Vista; and (2) the junction of the Cross-Delta Canal and the San Joaquin River, near the southeastern tip of Venice Island.

Inasmuch as salinity records at these key locations were not available, the salinity at reference locations downstream therefrom were related to the salinity at Antioch. Plate 29, "Relationship of Salinity at Antioch to Salinity at Rio Vista", shows the relationship of salinity at Antioch to salinity at the Rio Vista bridge (which is at the City of Rio Vista and about two miles downstream from one of the key locations). Salinities are in parts chlorides per million parts water and are random selections of recorded salinities taken one and one-half hours after higher high tide, from 1921 through 1960. Plate 30, "Relationship of Salinity at Antioch to Salinity at Mouth of Mokelumne River", shows this relationship for the location downstream from the second key location. Although points on each of the plates are quite scattered, the trend of the relationship is evident. At the lower salinities, where the scatter of points is greatest, other factors which influence the quality of the water become more prominent and the effect of saline water incursion is less definable.

To determine the average salinity of water at these two key locations for a given outflow from the Delta, Plates 15 and 16 were utilized. As an example, if the outflow from the Delta was 1,000 second-feet, the mean tidal cycle surface zone salinity at Antioch (from Plate 15) would be 2,800 ppm chlorides. The surface zone salinity one and one-half hours after higher high tide at Antioch would be 4,100 ppm chlorides (from Plate 16). Entering Plates 29 and 30 with 4,100 ppm chlorides surface zone salinity at Antioch, the salinity at Rio Vista one and one-half hours after high high tide would be 270 ppm chlorides, and at the mouth of the Mokelumne River one and one-half hours after high high tide would be 200 ppm chlorides. Converting salinities at one and one-half hours after higher high tide to mean tidal cycle surface zone salinity gives 150 ppm chlorides at Rio Vista and 105 ppm chlorides at the mouth of the Mokelumne River. Salinities at these locations are higher than the water quality objectives for chlorides in the water for export from the Delta. Water quality objectives for water exported from the Delta are given in Chapter VI. Because of the salinity gradient existing in the river (i.e., a decrease in salinity with increasing distance from the source of the salinity) the salinity in terms of chlorides at the key locations would be less than the maximums specified in the water quality objectives. Mean salinity would be about 80 ppm at Junction Point and considerably less at the junction of the Cross-Delta Canal and the San Joaquin River.

The minimum uncontrolled outflow from the Delta with the Comprehensive Delta Water Project in operation would be approximately 750 second-feet in the month of peak water use. The uncontrolled flow to Suisun Bay would consist of drainage discharges returned to the channels downstream from the control structures or at locations where such returns could not be recovered for reuse, and fishway and lockage losses. On the Sacramento River, fishway and lockage losses were estimated at 120 second-feet, and drainage discharges returned to the channels from the islands below the control structures on Steamboat Slough and the Sacramento River were estimated at 50 second-feet, for a total uncontrolled flow of 170 second-feet. Inflow at Vernalis, on the San Joaquin River, was assumed to be 500 second-feet. Drainage returns upstream from the junction of the Cross-Delta Canal and San

Joaquin River were estimated to be 195 second-feet, with diversions between the junction and Vernalis estimated to be 525 second-feet. Flow in the San Joaquin River past its junction with the Cross-Delta Canal was about 175 second-feet. Estimated drainage discharges to the channels downstream from the Cross-Delta Canal were about 320 second-feet and the estimated fishway release was approximately 90 second-feet. The total uncontrolled flow in the San Joaquin River was thus estimated at 580 second-feet. The minimum discharge from the Delta was the sum of the uncontrolled flows on both rivers; which was about 750 second-feet. Since this outflow would not sustain good quality water at the two key locations mentioned previously, the minimum outflow for the project was increased to 1,000 second-feet. With an outflow to Suisun Bay of 1,000 second-feet, salinity incursion would not be detrimental to the water exported from or used in the Delta under operation of the Comprehensive Delta Water Project.

The 1,000 second-feet of outflow to Suisun Bay was divided between the two rivers in proportion to the tidal flows into and out of each river system. From the discussion of distribution of tidal flows in Chapter II it was noted that about 40 percent of the tidal flow is in the Sacramento River system and about 60 percent of the flow is in the San Joaquin River. If these percentages of outflow are maintained, then outflow in the Sacramento and San Joaquin Rivers would be respectively 400 and 600 second-feet; thus, the controlled release in each river would be the difference between the uncontrolled outflow and the required outflow.

An estimate was made of the quantity of stored water that would have to be released to meet Delta outflow requirements to operate the Delta water facilities. Inasmuch as all alternatives of the Delta Water Project require a minimum 1,000 second-feet of outflow from the Delta for operation, the quantity of stored water released for each alternative would be the same. An operation study for the 20-year water supply period for each 20-year condition of development was used to determine the quantity of stored water released for outflow from the Delta. The quantity of storage releases for salinity control increases with time because more and more of the uncontrolled flows are captured for use both upstream from and in the Delta, and for export from the Delta.

Salinity Conditions in Western Delta Channels

Salinity conditions in channels of the Western Delta were determined from estimates of outflow from the Delta and the salinity incursion-Delta outflow relationship shown on Plate 15. Outflows were estimated for each month for the 20-year period 1922-41, for seven conditions of development in the Central Valley; natural, present, 1970, 1980, 1990, 2000, and 2020. With the outflow from the Delta for each month for a given condition of development, salinity at five locations in the Western Delta was determined. The five locations were Mallard Slough, Antioch, Jersey Point, Collinsville, and Emmaton. The percent of time that salinity of the channel water was less than 100, 150, 250, 350, 500, and 1,000 parts chlorides per million parts water was determined at each of the 5 locations. Plate 31, Sheets 1 and 2, "Natural, Present, and Future Salinity Conditions in Western Sacramento-San Joaquin Delta", show the percent of time salinity of water in the rivers is less than 150, 350, and 1,000 ppm chlorides at each of the 5 locations for natural, present, 1990, and 2020 conditions of development.

From the plate it is observed that the availability of water from the rivers of a salinity less than a given chloride content decreases in time. The average annual availability of water less than 1,000 ppm chlorides decreases from about 94 percent under natural conditions to 20 percent under 2020 conditions of development. The average annual percent availability was taken as the average of the monthly percentages. There is a greater availability of water of less than 1,000 ppm chlorides than of water less than 150 ppm chlorides, and there is a greater availability at the locations further upstream, such as Jersey Point and Emmaton, than at Mallard Slough. Under 2020 conditions of development, and a minimum outflow of 1,000 second-feet, there would be water of less than 1,000 ppm chlorides available at Jersey Point 100 percent of the time, whereas at Mallard Slough, 1,000 ppm chlorides water or better would be available about 18 percent of the time.

Data on the percent time water in the rivers would contain salinity less than the other chloride concentrations previously mentioned for other conditions of development are not included but are available in the back-up data for this report.

An analysis was made of the data to compare the difference between the percent time water of a specific salinity was available for the 20-year period to the percent time it was available for the 50-year period, 1907-08 to 1956-57, which was considered a long-term mean period. Using inflows to the Delta from the major tributary streams for natural conditions, the difference in percent of time that water of a given quality was available for each period was determined. It was found that the average annual availability of water for the 20-year period was about 8 percent less than for the 50-year period for natural conditions of development. Availabilities shown in Bulletin No. 76 are based on the 50-year water supply period.

As more of the natural water supply is used in the future, the quantity of water wasting to Suisun Bay will diminish and by 2020 the outflows from the Delta for the 2 periods will be about the same, so the availability of water of a particular concentration in the rivers should be about the same at that time. In the economic evaluation of changes in water supply brought about by the Delta water facilities, this factor of difference in the 20-year to the 50-year period of water availability was considered.

Typical Alternative Delta Water Project

Since certain facilities of the Comprehensive Delta Water Project are not presently economically justified, a lesser plan such as the Typical Alternative Delta Water Project could be constructed. This plan would not include flood control and seepage features south of the San Joaquin River. Plate 32, "Typical Alternative Delta Water Project", shows the features included in the plan.

North of the San Joaquin River, the features are the same as the Comprhensive Delta Water Project with a lock, control structure, and a fishway at Ryde on the Sacramento River; control structures downstream from the junction of the two sloughs adjacent to Sutter Island on Steamboat Slough; headworks to the Cross-Delta Canal, a fish screen at Walnut Grove on the Sacramento River; and a master levee along the South Fork of the Mokelumne River which serves as the Cross-Delta Canal. Master levees would be constructed along the north bank of the San Joaquin River to tie into the existing San Joaquin River Flood Control Project, and the Bear Creek Diversion would be retained.

South of the San Joaquin River, the control structure on Holland Cut, the slough immediately south of Franks Tract would be retained, and only four closures on other sloughs would be made, two on Fishermans Cut (the slough between Bradford Island and Webb Tract), and at two other locations. Three closures would be to deter saline water of high chloride content from easily mixing with the water crossing the Delta for use in the southern portion of the Delta and for export.

Under this plan, water moving toward the pumping plants at the southern part of the Delta would do so through about all of the present channels rather than being restricted to a single channel, as in the Comprehensive Delta Water Project. With this plan, conflict with recreational interests and others opposed to channel closures in the area south of the San Joaquin River would be minimized. Replacement water facilities for providing good quality water for agricultural, municipal, and industrial water users would also be provided with facilities similar to the Comprehensive Delta Water Project.

Second stage features similar to those of the Comprehensive Delta Water Project, and as shown in Bulletin No. 76, could also be constructed as part of the Typical Alternative Project if economically justified.

Summer Operations

Operation of the Typical Alternative Delta Water Project in summer months or at other times when the project is operated for water supply and water transfer would be similar to operation of the Comprehensive Delta Water Project. South of the San Joaquin River, however, the distribution of flows in the channels would be different from the Comprehensive Delta Water Project because more of the sloughs and waterways would be available to carry the flows toward the pumping plants. Plate 33, "Typical Alternative Delta Water Project Summer Flow Distribution", shows the distribution of flows in the Delta to meet the estimated ultimate Delta and export demands.

Winter Operations

Winter operation in the Delta north of the San Joaquin River would be about the same as operation of the Comprehensive Delta Water Project north of the San Joaquin River. Flood flow would be restricted to specific channels. South of the San Joaquin River the gates of the control structure on Holland Cut would be opened and about all of the present channels would be utilized to discharge the flood flows to the downstream reaches of the San Joaquin River for eventual discharge to the bays and thus to the Pacific Ocean. Because of closures on the waterways southwest of Medford and Mandeville Islands, dredging on other waterways leading into the San Joaquin River will be made to handle flood flows without increasing flood stages over present stages in the area south of the San Joaquin River. Plate 34, "Typical Alternative Delta Water Project, Winter Flow Distribution", shows schematically the distribution of design flood flows through the Delta.

Tidal Conditions

Extensive studies of tidal conditions for the Typical Alternative or the Single Purpose Delta Water Projects were not conducted on the electronic analog model by personnel at the University of California. However, department personnel did conduct comparisons of tidal conditions in the Delta. These comparisons indicated that the increase in tidal amplitudes at the control structures on the Sacramento River for the Typical Alternative Delta Water Project were a few tenths of a foot less than for the Comprehensive Delta Water Project. Tidal amplitudes along the San Joaquin River for the Typical Alternative Delta Water Project were increased only slightly over existing tidal amplitudes. It, therefore, seemed reasonable to suppose that because of indicated smaller tidal amplitude increases with less channel area removed from tidal influence, the tidal prism on the Delta for this project would remain about as it is at present. Thus, outflow to control salinity under operation of the Typical Alternative Delta Water Project would not significantly change the present outflow salinity relationships shown on Plate 15.

Outflow to Operate Project

Since the operation of the Typical Alternative Delta Water Project is similar to the operation of the Comprehensive Delta Water Project and the same Delta outflow-salinity incursion relationship applies to both projects, the minimum outflow to operate each project should be the same. Control of salinity at the two key locations mentioned in the previous discussion of "outflow to Operate Project" for the Comprehensive Delta Water Project would be required for this project. Therefore, outflow to Suisun Bay of 1,000 second-feet, with 400 second-feet in the Sacramento River and 600 second-feet in the San Joaquin River would be the minimum required. The minimum uncontrolled outflow would be about the same as for the Comprehensive Delta Water Project.

Salinity Conditions in Western Delta Channels

Salinity conditions in the Western Delta channels under operation of the Typical Alternative Delta Water Project would be the same as under operation of the Comprehensive Delta Water Project because the minimum outflow and water supply and demand would be the same. Plate 31, indicates this condition.

Single Purpose Delta Water Project

The minimum facilities which can be constructed in the Delta to provide an adequate water supply and enable the export of good quality water would be those included in the Single Purpose Delta Water Project.

This project would not include any features for flood or seepage control. Plate 35, "Single Purpose Delta Water Project", shows the features of this project. Control structure, locks, fisheries, and headworks for diverting Sacramento River water into the Mokelumne River would be similar to the other projects. The essential differences in this project over the other two is that both the North and South Forks of the Mokelumne River, as well as Georgiana Slough, the waterway immediately east and running in the same general southwesterly direction as the forks of the Mokelumne River, would be used in transferring water across the Delta; there would be a control structure and small craft lock on the Mokelumne River immediately downstream from the junction of its two forks and Georgiana Slough; and all closures would be eliminated except those shown. The Bear Creek Diversion would not be constructed and flood flows from Bear Creek would pass through existing Delta channels. Closures as shown would be necessary for controlling the quality of water to be exported from the Delta and used therein. Facilities would be included for providing water to the users in the Western Delta for river supplies degraded because of the higher concentrations of saline water due to reduced outflows. These facilities would be about the same as in the previously discussed projects.

Second stage features for the Single Purpose Delta Water Project could be constructed as shown in Bulletin No. 76 if economically justified.

Summer Operations

Operation of the Single Purpose Delta Water Project in summer months, or at other times when the project is operated for water supply and water transfer, is similar to operation of the Comprehensive Delta

Water Project when operated for the same purposes. Gates of the control structure on the Mokelumne River would be closed, as would those at the structures on Steamboat Slough and the Sacramento River. Water from the Sacramento River flowing into Georgiana Slough and the North Fork of the Mokelumne River exits into the sloughs east of and adjacent to Bouldin Island via the arm of the South Fork of the Mokelumne River north of Bouldin Island. These flows mix with the water in the San Joaquin River and pass into the channels south of the San Joaquin River and, thence on to the pumping plants. Plate 36, "Single Purpose Delta Water Project, Summer Flow Distribution", schematically indicates the magnitude and direction of flows throughout the Delta under summer operations. Delta consumptive use of 5,100 second-feet and maximum design capacities of export facilities, were used in determining the distribution of flows.

Winter Operations

Operations of the Single Purpose Delta Water Project would not change existing winter conditions in the Delta. Gates on all control structures would be opened and the distribution of flows in the channel would be as shown on Plate 37, "Single Purpose Delta Water Project, Winter Flow Distribution". Flood flows would not be restricted to specific channels, but of the flood flows in Georgiana Slough and the North and South Forks of the Mokelumne River, 25,000 second-feet would be discharged through the control structure on the Mokelumne River, and the remaining flow of 41,000 second-feet, would be discharged to the San Joaquin River through the slough lying between Bouldin Island and Terminous Tract, and Venice Island and Empire Tract. The design flood flows entering the Delta are the same as the flows used for the other projects.

Tidal Conditions

Tidal conditions in the Delta, as a result of construction and operation of the Single Purpose Delta Water Project, would not change appreciably from present conditions. Extensive tidal studies on the electronic analog model were not made for the Single Purpose Delta Water Project but the first approximation of such on the analog indicated tidal amplitudes at the control structures in the Sacramento River system would be increased by only a few tenths of a foot less than under the Comprehensive Delta Water Project. Along the San Joaquin River, tidal amplitudes would remain about as they are at present. Thus it appears that the tidal prism in the Delta, with facilities of the Single Purpose Delta Water Project constructed, would be about the same as at present. Outflow to control salinity would, therefore, be the same under project conditions as for present conditions.

Outflow to Operate Project

Outflow to Suisun Bay to operate the Single Purpose Delta Water Project would be the same as for the Comprehensive and Typical Alternative Delta Water Project, 1,000 second-feet. Division of outflow between the Sacramento and San Joaquin Rivers would be the same, as the minimum uncontrolled outflow would be about the same as the other projects.

Salinity Conditions in Western Delta Channels

Salinity conditions in the Western Delta channels under operation of the Single Purpose Delta Water Project would be the same as under operation of the Comprehensive Delta Water Project because the minimum outflow and water supply and demand would be the same. Plate 31, indicates this condition.

Chipps Island Barrier Project

The Chipps Island Barrier Project would provide a physical barrier to separate fresh water in the Delta from saline water in the Bay. There would not be any works constructed in the Delta for flood or seepage control or improvements in transportation as a result of master levees and channel closures. Plate 38, "Chipps Island Barrier Project" depicts the features of this project.

There would be a floodway structure, navigation lock, and fishway across the Sacramento River near Pittsburg. Master levees around the Suisun Bay area would be required because of increased tidal amplitudes; these will be discussed later. A barge lock would also be required on Montezuma Slough, north of Suisun Bay.

Summer Operations

As with other proposed projects in the Delta, the Chipps Island Barrier Project would be operated in the summer months for water supply and water transfer. The range in maximum elevation of water levels in the channels resulting from these operations would be limited to about three feet. The lower elevations would be about one foot below mean sea level to minimize dredging for navigation, and the upper elevation would be about two feet above mean sea level to minimize seepage and levee stability problems.

Plate 39, "Chipps Island Barrier Project, Summer Flow Distribution", schematically shows the distribution of flow through the Delta channels for summer conditions. Water to be exported from the Delta would be directed through the channels of the Wester Delta to remove heat and maintain satisfactory water quality conditions. Water users would divert their water supplies directly from the river as is presently done, and replacement works would not be required. Flows into the Mokelumne River from the Sacramento River would be held to a minimum, but sufficient to supply water demands in that area of the Delta.

Winter Operations

In winter months, or times when flood flows enter the Delta, the gates of the floodway structure would be open and flow conditions in the Delta would be as they exist presently. Plate 40, "Chipps Island Barrier, Winter Flow Distribution", indicates schematically, the distribution of design flood flows through the Delta with the Chipps Island Barrier Project in operation.

Tidal Conditions

With the gates of the floodway structure closed, tide would be eliminated from the Delta channels. Downstream from the floodway structure, however, there would be a change in tidal conditions. Studies conducted on the electronic analog model by the University of California provided data on the changes in tidal conditions that would be brought about in the bay as a result of construction of the Chipps Island Barrier.

Table 31, lists the tidal amplitudes of a typical spring tide at two locations in the bay, with and without a barrier at Chipps Island. The tidal amplitude at Chipps Island was doubled as a result of the barrier.

Table 32 lists the tidal amplitudes at Chipps Island for an unusual spring tide at the Golden Gate with and without a barrier at Chipps Island. The tidal amplitudes are listed in feet above the low low tide. The datum of low low tide was not determined on the analog model.

TABLE 31

EFFECTS OF CHIPPS ISLAND BARRIER
ON A TYPICAL SPRING TIDE

Location	Tidal amplitude, in feet	
	No barrier	With barrier
Selby	6.5	-
Chipps Island	4.9	9.0

TABLE 32

EFFECTS OF CHIPPS ISLAND BARRIER
ON AN UNUSUAL SPRING TIDE

Location	No barrier		With barrier
Golden Gate	High high	8.5[1]	8.5
	Low high	6.3	6.3
	High low	3.0	3.0
Chipps Island	High high	6.3[1]	12.0
	Low high	4.8	10.6
	High low	2.5	4.0

[1] Amplitude in feet above low low tide.

The actual magnitude of raising of the high water and lowering of the low water could not be determined on the analog, so that increase in tidal amplitude was assumed divided equally between raising and lowering of the high and low waters. Raising of the high water about 2.5 to 3.0 feet at Chipps Island dictated the construction of levees adjacent to Suisun Bay.

Outflow to Operate Project

Outflow to operate the Chipps Island Barrier Project would increase in time from about 750 second-feet in 1970, to about 1,850 second-feet in the year 2020. The outflow would consist of losses from lock and fishway operations. Flow to operate the fishway was estimated at 200 second-feet through the period 1970 through 2020, and lockage losses were estimated at 550 second-feet initially, increasing to about 1,650 second-feet in 2020. The greater lockage losses in 2020 would be due to increased shipping tonnage passing through the Chipps Island locks. Shipping tonnage would increase about fourfold from 1970 to 2020.

Salinity Conditions in Western Delta Channels

There would not be any salinity problem in the Western Delta channels as a result of the Chipps Island Barrier Project. The physical separation of the fresh-water flows of the rivers and the saline bays would make fresh water available at all locations upstream from the floodway structure.

Below the structure, however, there would be a salinity gradient with the outflow from the barrier keeping the salinity immediately downstream relatively fresh. However, the concentration of chlorides, progressing downstream, would increase rather rapidly.

CHAPTER VI. WATER QUALITY

If water delivered to an area of use is not of suitable quality for the intended uses, water development facilities involved in storing and delivering the water would not meet their objectives.

It is contemplated that Delta water facilities when constructed, would meet the objectives of providing good quality water by physically separating most of the inland fresh waters from saline bay waters. In so doing it is also anticipated that a substantial portion of the water presently discharged to Suisun Bay to repel the incursion of salinity may be salvaged. Concurrent with studies to determine the amounts of water that could be salvaged by operation of the Delta water facilities, studies have been made to predict the quality of water that would be available for diversion at various points of use within the Delta, as well as for export from the Delta to areas of deficiency.

Quality Criteria and Objectives for Waters to be Exported

Criteria for evaluating the suitability of water for the various anticipated uses have been promulgated by numerous agencies and associations. Even within the same general categories, recommended limiting concentrations of mineral constituents in water vary widely, depending upon the intended uses. For example, industrial quality requirements for cooling water are quite liberal; whereas, requirements for boiler make-up waters are quite exacting. Similarly, recommended limiting concentrations for the same constituent may be considerably different if the water is to be used for drinking or for an agricultural supply. Discussions of water quality requirements are included in the companion appendix "Delta Water Requirements". Water quality requirements are also discussed in reference 28 of this appendix.

State Water Resources Development System

Because of the wide variations in water quality requirements, the State Water Resources Board retained a board of consultants to recommend specific limiting values for the more important constituents and characteristics for water to be exported from the Sacramento-San Joaquin Delta under operation of the proposed State Water Resources Development System.

This board held public meetings to obtain recommendations and suggestions from federal, state, and local agencies; agricultural and industrial consultants; and associations and societies concerned with water quality. In developing recommended limiting concentrations, the board considered that allowances must be made for progressive increases in agricultural and industrial development in areas of surplus supply as well as for attendant population increase; and further, that waters flowing in all portions of the system should be of satisfactory quality to meet the intended uses without requiring extensive treatment. The board, however, refrained from recommending specific limits for indices of contamination or for constituents bearing directly on fish and wildlife. Limits for these constituents are subject to regulation by the water pollution control boards and the State Departments of Public Health and Fish and Game.

Table 33 lists the recommended limiting concentrations for certain mineral constituents and other water quality characteristics, adopted by the board of consultants.

TABLE 33

QUALITY LIMITS RECOMMENDED FOR WATER TO BE EXPORTED BY THE STATE FROM THE SACRAMENTO-SAN JOAQUIN DELTA

Item	Limit
Total dissolved solids	400 ppm*
Electrical conductance	600 micromhos at 25°C
Hardness as $CaCO_3$	160 ppm
Sodium (percentage)	50%
Sulfate	100 ppm
Chloride	100 ppm
Flouride	1.0 ppm
Boron	0.5 ppm
pH value	7.0-8.5
Color	10 ppm
Other constituents as to which the U. S. Public Health Service has or may establish mandatory or recommended standards for drinking water	USPHS Limits

* ppm (parts per million)

In presenting these recommendations, the Board of Consultants on Water Quality stated:

> "It is the opinion of this Board that the limits set forth will permit full agricultural development in northern California, provide for greatly increased population in that area, and allow the establishment of all industries required for the support of that population. It is the further opinion of this Board that these limits will permit

> the use of this water for agricultural purposes without detrimental effects, and enable this water to be used for domestic and industrial purposes without placing any undue burden upon the distributors or users."

The recommendations of the board, as presented in the foregoing tabulation, are presented in Reference 16, and have been adopted by the Department of Water Resources as quality objectives to be met at points of diversion for water to be exported from the Delta to areas of deficiency.

In general, the limits recommended are more restrictive than either the drinking water standards adopted by the United States Public Health Service in 1946 or the irrigation criteria suggested by the Regional Salinity Laboratory of the United States Department of Agriculture in their pamphlet (Ref. 57).

Metropolitan Water District Contract. The Metropolitan Water District of Southern California will be one of the major purchasers of water exported from the Delta by means of the proposed State Water Facilities. Water quality objectives have been incorporated into the contract with this district to the effect that the State shall take all reasonable measures to make available water of such quality that the constituents do not exceed the concentrations listed in Table 34.

TABLE 34

WATER QUALITY OBJECTIVES FOR METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA [1]

Constituent	Unit	Monthly average	Average for any 10-year period	Maximum
Total dissolved solids	ppm	440	220	---
Total hardness	ppm	180	110	---
Chlorides	ppm	110	55	---
Sulfates	ppm	110	20	---
Sodium percentage	%	50	40	---
Fluoride	ppm	---	---	1.5
Lead	ppm	---	---	0.1
Selenium	ppm	---	---	0.05
Hexavalent chromium	ppm	---	---	0.05
Arsenic	ppm	---	---	0.05
Iron + Manganese	ppm	---	---	0.3
Magnesium	ppm	---	---	125
Copper	ppm	---	---	3.0
Zinc	ppm	---	---	15
Phenol	ppm	---	---	0.001

[1] From contract between the State of California, Department of Water Resources and the Metropolitan Water District of Southern California for a water supply, November 4, 1960.

United States Bureau of Reclamation

The United States Bureau of Reclamation presently diverts water from the Sacramento-San Joaquin Delta to supply water to the Contra Costa and Delta-Mendota Canals. Certain quality considerations have been incorporated into contracts for delivery of water from these canals.

Contra Costa Canal. The only quality provision in this contract indicates that the United States assumes no responsibility for the quality of water to be furnished pursuant to the contract and does not warrant the quality of any such water; however, the water users are not obligated to accept and pay for any water which contains chlorides in excess of 250 ppm.

Delta-Mendota Canal. Under the Amended Exchange Contract of March 17, 1956 there is a provision that the quality of water supplied to diverters between Mendota and Newman, as determined by total dissolved solids, will not exceed the weighted mean values shown in Table 35.

TABLE 35

WATER QUALITY REQUIREMENTS FOR
WATER SERVED FROM DELTA-MENDOTA CANAL

Time interval	Total dissolved solids (ppm)
Daily	800
Monthly	600
Annually	450
Five years	400

Historic Water Quality Conditions

For purposes of water quality considerations in this chapter, historic conditions have been considered in two parts, past and present conditions. Past conditions are considered to be those which existed prior to construction and operation of the Central Valley Project. Present conditions in the Sacramento River portion of the Delta are considered to be those which have existed since the mid-1940's when Shasta Dam commenced regulating flows in the Sacramento River. For the San Joaquin River portion of the Delta, present conditions are considered to be those which have existed since the Tracy Pumping Plant for the Delta-Mendota Canal was placed in operation in June of 1951.

Mineral Quality of Water Supplies

Table 36 presents minimum, maximum, and weighted mean mineral quality values for the Sacramento River at Sacramento, and San Joaquin River at Vernalis under historic conditions. Weighted mean mineral quality values are values determined by weighting the concentration of the mineral constituent in proportion to the flow of water at the time of sampling. In addition, historic maximum and minimum mineral quality values for waters at several internal locations within the Delta are shown in Table 37. Weighted mean values of quality cannot be computed for these internal stations since flow data were not available for the sampling period. Minimum, maximum, and mean historic values of water quality are shown in Table 38 for water exported from the Delta via the Delta-Mendota Canal. The quality of water diverted into the Contra Costa Canal which was used in the economic considerations is shown and described in the companion appendix on "Economic Aspects".

TABLE 36

PAST AND PRESENT WATER QUALITY VALUES FOR TRIBUTARY STREAMS TO DELTA [1]

Constituent	Past	Present
Sacramento River at Sacramento		
Total dissolved solids		
Mean	NR	90 ppm
Minimum-Maximum	40-400 ppm	40-210 ppm
Total hardness		
Mean	NR	50 ppm
Minimum-Maximum	20-210 ppm	20-140 ppm
Chlorides		
Mean	NR	10 ppm
Minimum-Maximum	5-85 ppm	5-25 ppm
Sulfates		
Mean	NR	10 ppm
Minimum-Maximum	5-30 ppm	5-30 ppm
San Joaquin River at Vernalis		
Total dissolved solids		
Mean	300 ppm	190 ppm
Minimum-Maximum	50-900 ppm	50-740 ppm
Total hardness		
Mean	NR	NR
Minimum-Maximum	NR	NR
Chlorides		
Mean	80 ppm	50 ppm
Minimum-Maximum	5-180 ppm	5-290 ppm
Sulfates		
Mean	NR	NR
Minimum-Maximum	NR	NR

---

[1] NR indicates insufficient data on record to make proper evaluation.

TABLE 37

PAST AND PRESENT WATER QUALITY VALUES
FOR
INTERNAL CHANNELS OF DELTA

Constituent	Past	Present
Delta Cross Channel		
Total dissolved solids		
Minimum-Maximum	NR	70-180 ppm
Total hardness		
Minimum-Maximum	NR	30-90 ppm
Chlorides		
Minimum-Maximum	NR	5-20 ppm
Sulfates		
Minimum-Maximum	NR	5-20 ppm
Sacramento River at Rio Vista		
Total dissolved solids		
Minimum-Maximum	NR	70-205 ppm
Total hardness		
Minimum-Maximum	NR	40-125 ppm
Chlorides		
Minimum-Maximum	NR	5-30 ppm
Sulfates		
Minimum-Maximum	NR	5-20 ppm
San Joaquin River at Venice Island		
Total dissolved solids		
Minimum-Maximum	NR	85-480 ppm
Total hardness		
Minimum-Maximum	NR	40-220 ppm
Chlorides		
Minimum-Maximum	NR	20-145 ppm
Sulfates		
Minimum-Maximum	NR	10-75 ppm

TABLE 38

PRESENT RANGES OF WATER QUALITY VALUES FOR SOURCES OF EXPORT FROM DELTA

Constituent	Present
Delta-Mendota Canal	
Total dissolved solids	
Mean*	522 ppm
Minimum-Maximum	81-643 ppm
Total hardness	
Mean	NR
Minimum-Maximum	NR
Chlorides	
Mean*	85 ppm
Minimum-Maximum	16-258 ppm
Sulfates	
Mean	NR
Minimum-Maximum	NR

* Arithmetic Mean

In addition to the above-mentioned water quality data, many other sources (Refs. 23 and 24) provide information on historic water quality within the Delta.

Sources of Degradation

It can be seen by comparing the general quality of inflowing water with mineral qualities of water in various locations throughout the Delta, that waters are being degraded in transit across the Delta. Factors contributing to this degradation under present conditions are generally municipal and industrial waste discharges, irrigation return drainage, and the incursion of sea water. Since, under future operation of Delta Water Projects, it is assumed that sea-water incursion will be controlled so as to minimize degradation of water used for export and Delta uses, only the first two sources of degradation were accounted for in predicting future quality of water within the Delta.

Evaluation of waste discharge data has indicated that quantities of salts discharged by various communities containing both domestic and industrial activities can be correlated with the contributory population. Calculations of future quantities of waste discharges were based on projected populations within the Delta.

Evaluation of data collected during an investigation of irrigation and drainage water in the Delta during 1954 and 1955 has shown that the annual quantity of drained salts is related to the annual quantity of applied salts. Under present conditions it was shown that drained salts are about 20 percent in excess of applied salts annually, but that the discharge of drained salts through the months is not constant (Ref. 13). It was found that most of the salts applied during the irrigation season were retained in the soil to be released during the winter months when flushing flows of precipitation and seepage removed them. This same method of storing a portion of salts applied each month, with subsequent release during the winter, was utilized in predicting the future degradation of quality of water in the Delta.

Future Water Quality Conditions

Predictions were made of future quality of water that might exist in various locations throughout the Delta under full operation of the "Comprehensive Delta Water Project" in both 1970 and 1990 levels of development. Hydrologic conditions for the period from 1922 through 1941 were assumed. An office report entitled "Salt Routing Techniques with Applications of Machine Computing for Estimating Future Quality of Water Under Operation of 'The Comprehensive Delta Water Project'", is being prepared to explain in detail the entire process utilized for making predictions of future water quality conditions presented herein.

Predictions of future quality of water in the Delta were dependent upon results of salt-routing studies based upon flow data, plans for drainage disposal, and other operational criteria presently known or anticipated under project operations.

Mineral concentrations in the Sacramento River and other inflowing streams to the Delta were computed from equations of curves relating stream flow to mineral concentration. These "rating curves" have been developed for each of the major streams entering the Delta. These curves were developed from present and historical data and do not reflect any provision for possible changes in the future.

Accretions to salt loading of water flowing through the Delta were computed as a product of the quantity of accreting water and its mineral concentration, or as an independent accretion of salt. Factors required to make these computations were derived from evaluation of water quality records, and data on present physical conditions surrounding these various sources of salt accretions.

Results of these salt routings were in the form of computed mineral quality values at the 12 following locations, including inflow, internal, and export points of the Delta, for 240 consecutive months from January 1922 through December 1941, under both 1970 and 1990 levels of development:

Inflow	Sacramento River at Sacramento
	San Joaquin River at Vernalis
	Mokelumne River at Thornton
	Calaveras River at Stockton
Internal	Delta Cross Channel at head
	Sherman Island Irrigation deliveries
	Webb Tract irrigation deliveries
	Sacramento River at Rio Vista
	San Joaquin River at Venice Island
Export	North Bay Aqueduct
	Contra Costa Canal
	South Delta exports

In view of the fact that the present contract with the Metropolitan Water District for delivery of water from the Delta includes stipulations regarding mean quality throughout a 10-year period, the predictions of future quality conditions presented herein have been developed for selected 10-year periods. The period from 1924 to 1933 was found to be the 10 consecutive years of the 20-year study period during which total inflow to the Delta was the lowest, while the 10-year period from 1932 to 1941 was the one most nearly equal to the long-term mean, as well as the period of highest total inflow to the Delta during the 1922 to 1941 period. Computations of weighted mean qualities for all 11 of the 10-year periods showed that these 2 periods, noted as "dry" and "mean", developed the poorest and best average mineral qualities. Therefore, weighted mean qualities for total dissolved solids, total hardness, chlorides, and sulfates, were computed for both the "dry" and "mean" 10-year periods under both 1970 and 1990 conditions of development at each of the 12 aforementioned stations. Only the mean values for 1990 are shown in Table 39. Values for percent sodium were computed by relating total dissolved solids and total hardness.

Results of salt-routing studies utilizing anticipated procedures show that under 1990 conditions of development, water exported will, on a few occasions, exceed limitations set by the board for both total dissolved solids and total hardness. During the "mean" 10-year period (1932 to 1941), under 1990 conditons, approximately 3 percent of the total quantity of water exported from the south Delta will exceed quality limits recommended by the Board of Consultants on Water Quality. This is a small percent of the time and is less than the probable accuracy of the estimates of future water quality.

The studies were made for the Comprehensive Delta Water Project, but the results for the other projects would not be too far different if specific salt-routing studies for each project were conducted.

TABLE 39

ESTIMATED WATER QUALITY VALUES FOR SACRAMENTO-SAN JOAQUIN DELTA*

(1990 Conditions)
(Parts Per Million)

Location	Hydrologic period	Constituent				
		Total Dissolved Solids	Total Hardness	Chlorides	Sulfates	Percent Sodium
Sacramento River at Sacramento	dry	100	50	10	10	40
	mean	90	50	10	10	35
San Joaquin River at Vernalis	dry	290	130	90	30	50
	mean	160	70	40	20	50
Mokelumne River at Thornton	dry	190	110	10	10	30
	mean	150	80	10	10	40
Calaveras River at Stockton	dry	110	90	5	10	5
	mean	100	80	5	10	5
Delta-Cross Channel at Head	dry	110	60	10	10	35
	mean	100	50	10	10	40
Sherman Island Irr. Deliveries	dry	180	90	10	10	40
	mean	160	80	10	10	40
Webb Tract Irr. Deliveries	dry	200	100	20	15	40
	mean	180	90	20	15	40
Sacramento River at Rio Vista	dry	90	45	10	10	40
	mean	80	40	10	10	40
San Joaquin River at Venice Is.	dry	120	60	15	10	40
	mean	100	50	10	10	40
North Bay Aqueduct Exports	dry	180	100	20	10	35
	mean	170	90	20	10	40
Contra Costa Canal Exports	dry	170	90	30	15	40
	mean	160	80	25	15	40
South Delta Exports	dry	150	80	20	10	40
	mean	140	70	20	10	40

* All constituents reported as parts per million, except "Percent Sodium" which is reported as percentage of sodium ion, expressed in equivalents per million, to total cations.

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PLATE I

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DELTA BRANCH

◆

GENERAL AREA OF INVESTIGATION

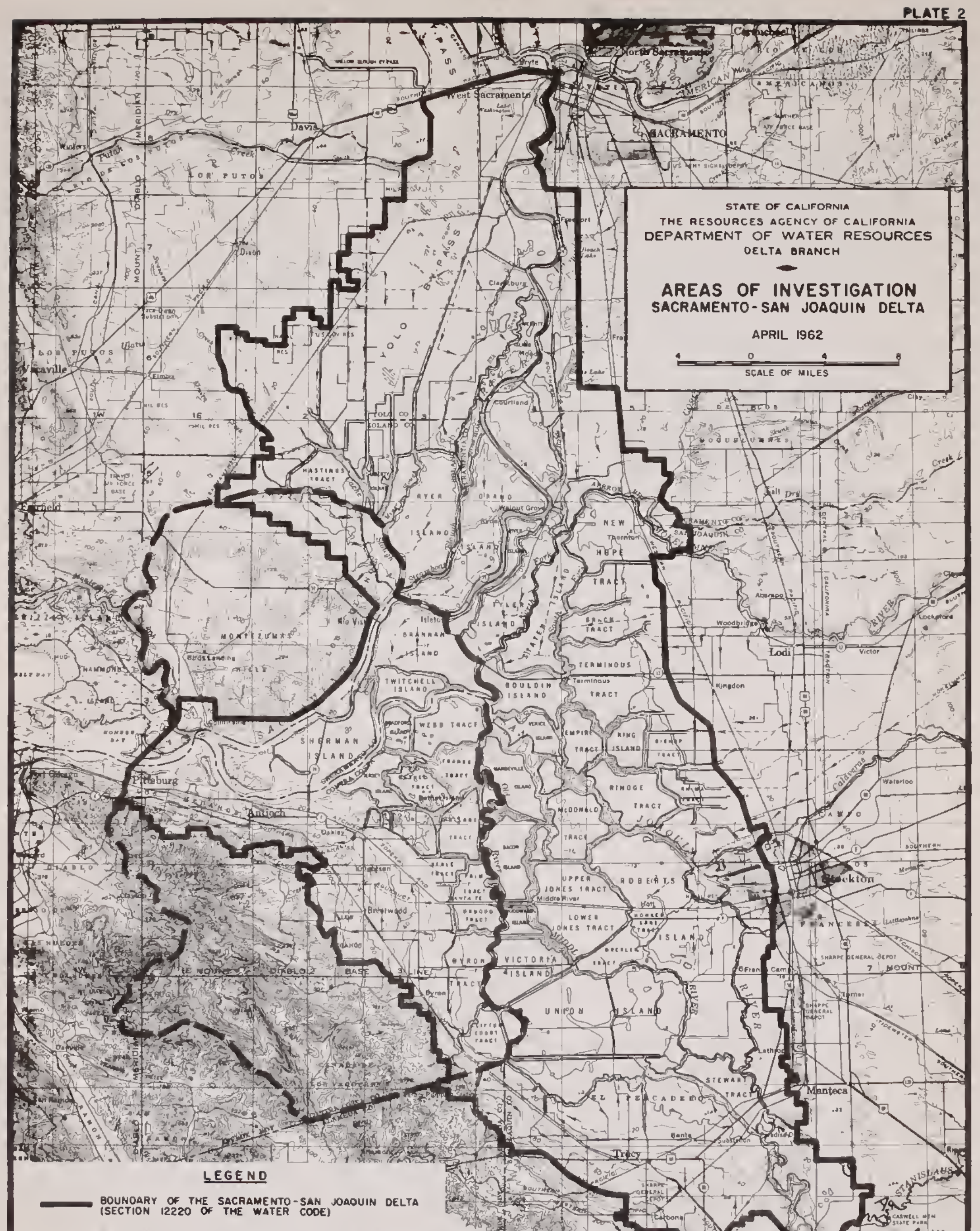
APRIL 1962

SCALE OF MILES
40 0 40 80

LEGEND

BOUNDARY OF GENERAL AREA

PLATE 2



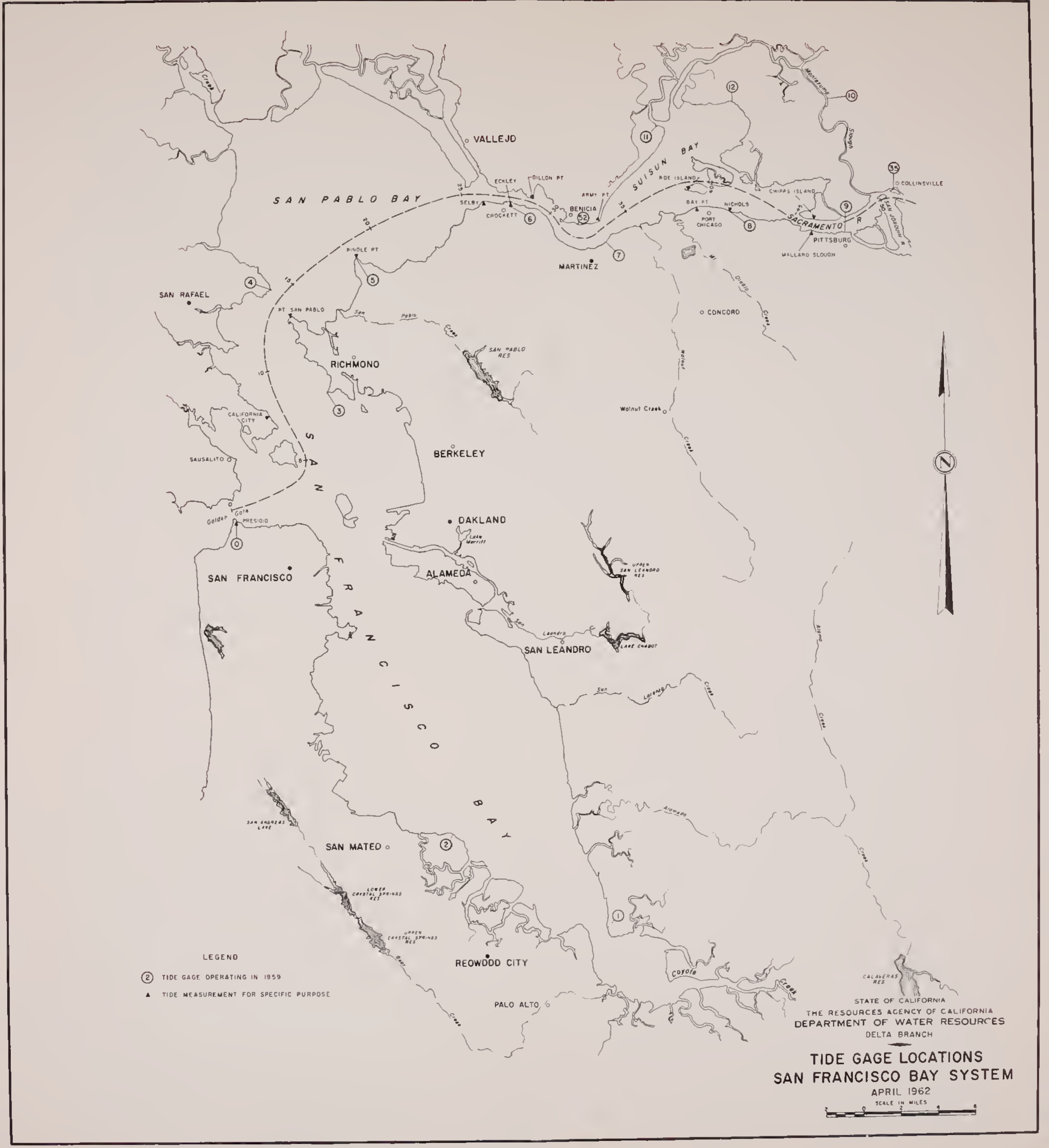
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DELTA BRANCH

AREAS OF INVESTIGATION
SACRAMENTO-SAN JOAQUIN DELTA

APRIL 1962

LEGEND

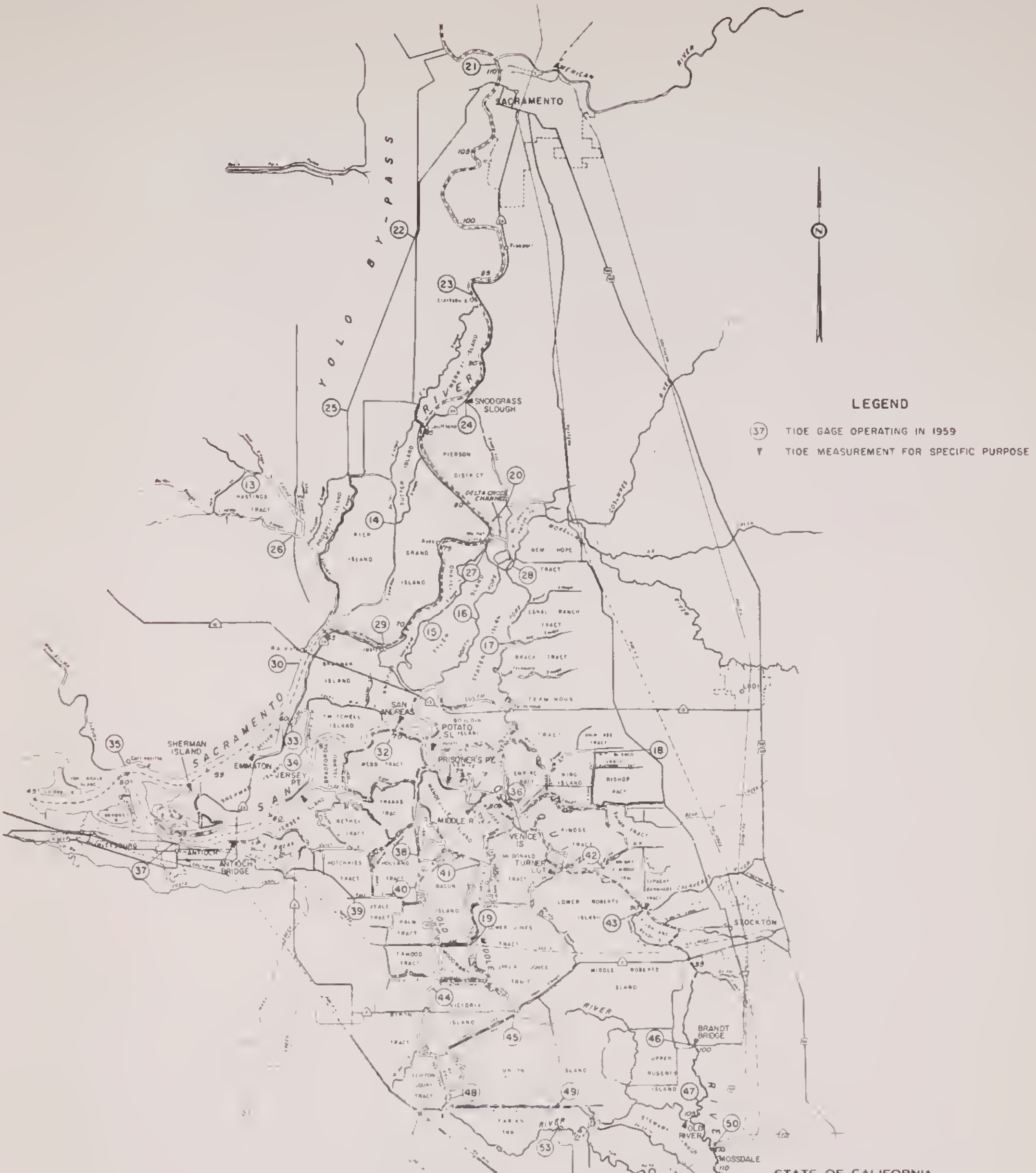
- BOUNDARY OF THE SACRAMENTO-SAN JOAQUIN DELTA (SECTION 12220 OF THE WATER CODE)
- BOUNDARY OF THE WESTERN DELTA STUDY AREA (AREA OF INTENSIVE STUDY OF WATER REQUIREMENTS AND SUPPLIES PURSUANT TO CHAPTER 1765, STATUTES OF 1959)



STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DELTA BRANCH

TIDE GAGE LOCATIONS
SAN FRANCISCO BAY SYSTEM

APRIL 1962



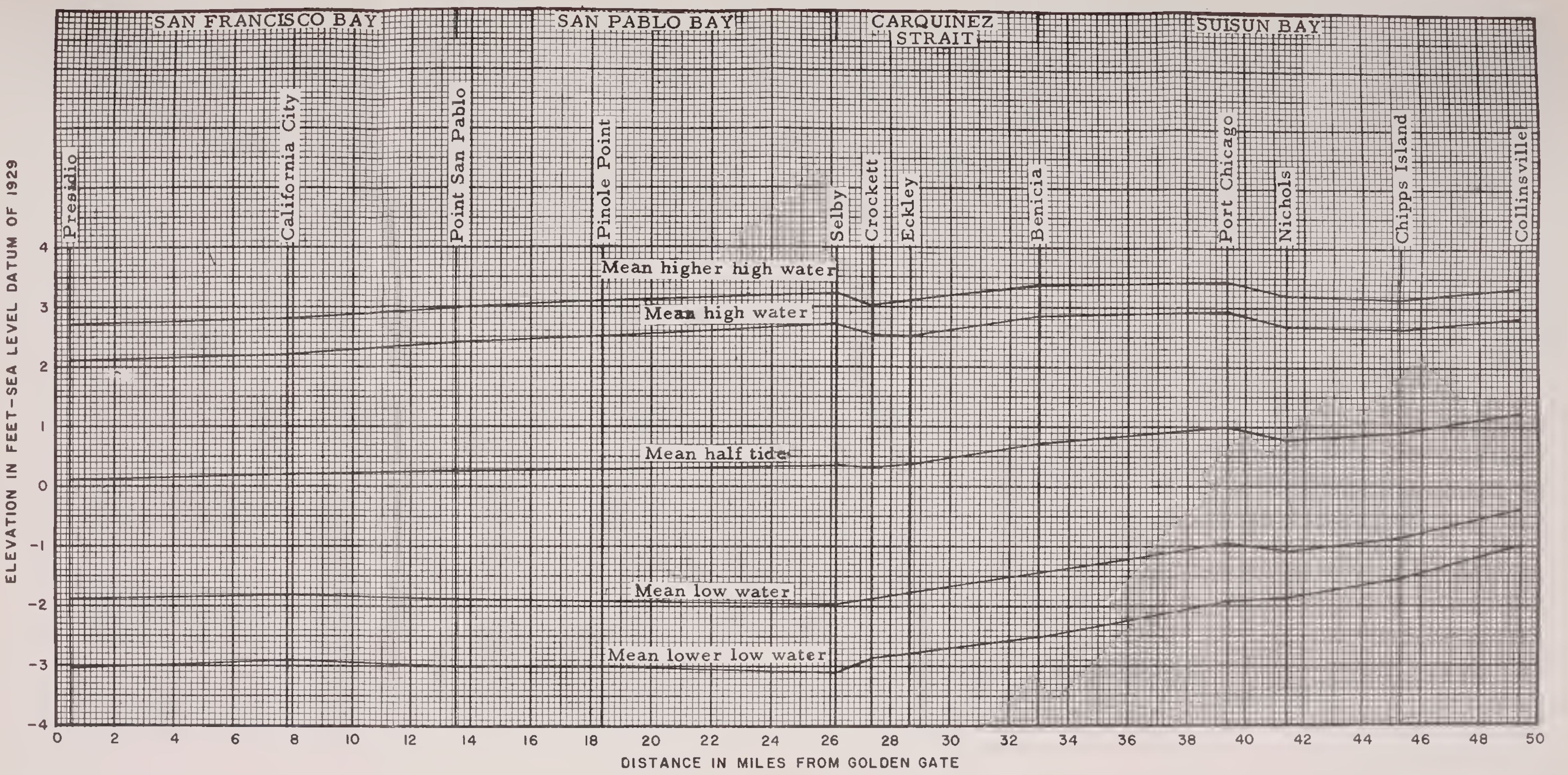
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DELTA BRANCH

TIDE GAGE LOCATIONS
SACRAMENTO-SAN JOAQUIN DELTA

APRIL 1962

SCALE OF MILES
2 0 2 4 6 8

PLATE 5



NOTE: Elevations at Point San Pablo, Eckley, and Nichols based upon tidal data obtained by predecessor agency of Department of Water Resources. All other elevations based upon data from U. S. Coast and Geodetic Survey.

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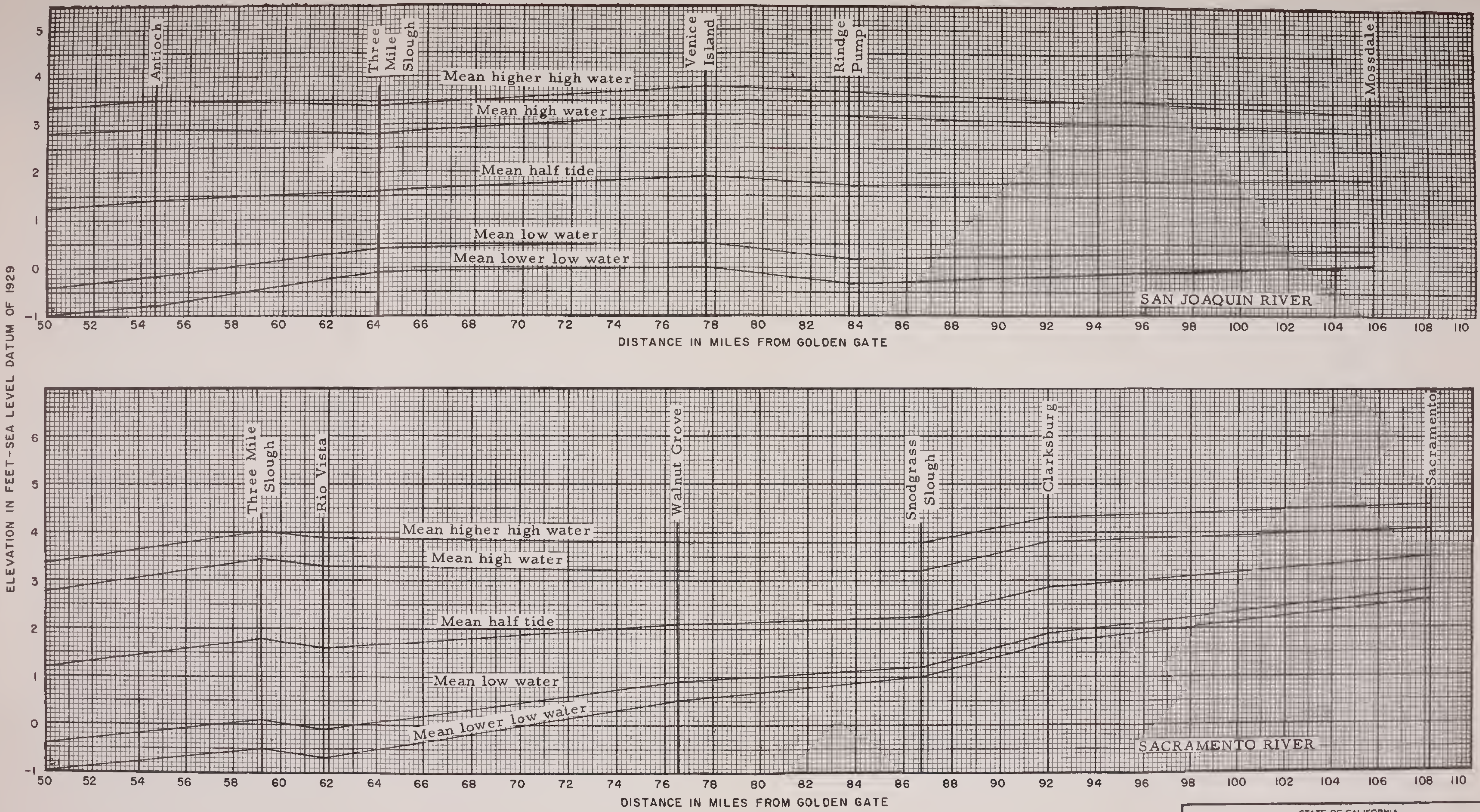
DELTA WATER FACILITIES

MEAN WATER SURFACE ELEVATIONS
NORTH SAN FRANCISCO BAY
APRIL 1962

PLATE 6



NOTE: Elevations based upon tidal records from July 15, 1953 to September 15, 1953 obtained by predecessor agency of Department of Water Resources.

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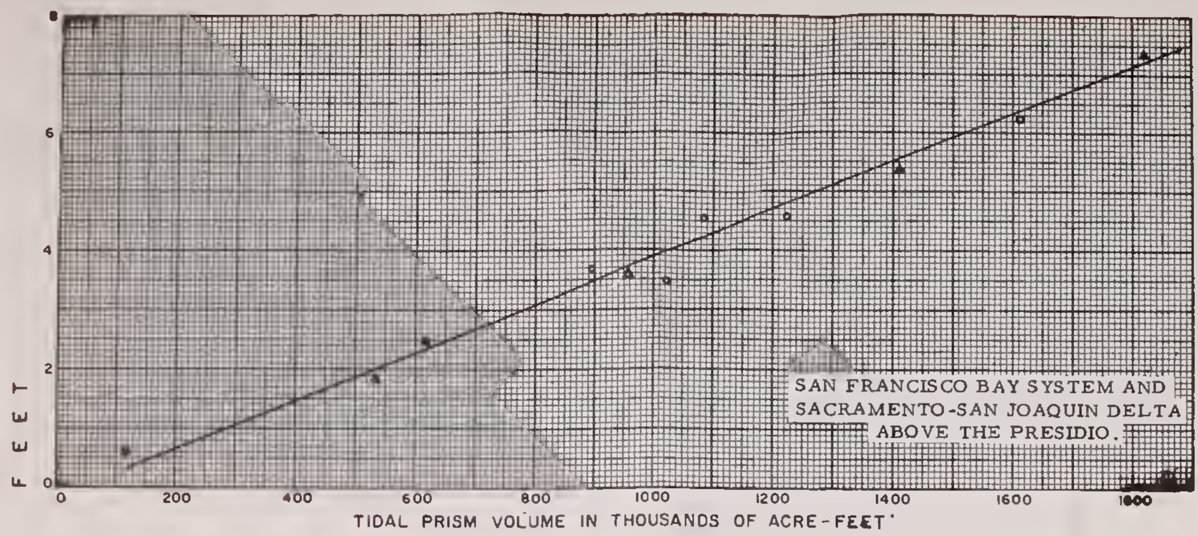
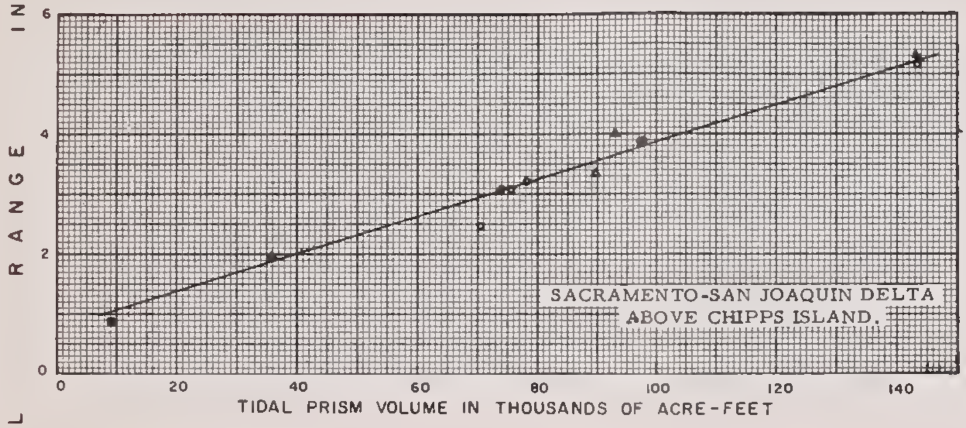
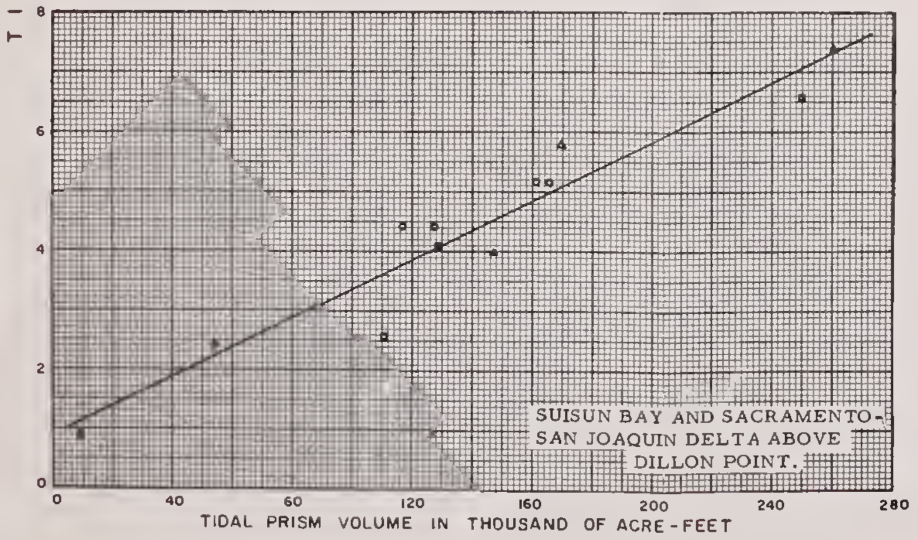
MEAN WATER SURFACE ELEVATIONS
SACRAMENTO - SAN JOAQUIN DELTA

APRIL 1962







LEGEND

Average Stream Flow:

□-- January 29 and 30, 1954,
Sacramento River at
Sacramento 55,600 cfs

San Joaquin River at
Vernalis 2,200 cfs

△-- February 1 and 2, 1954,
Sacramento River at
Sacramento 58,200 cfs

San Joaquin River at
Vernalis 1,900 cfs

○-- February 19 and 20, 1954,
Sacramento River at
Sacramento 68,000 cfs

San Joaquin River at
Vernalis 3,500 cfs

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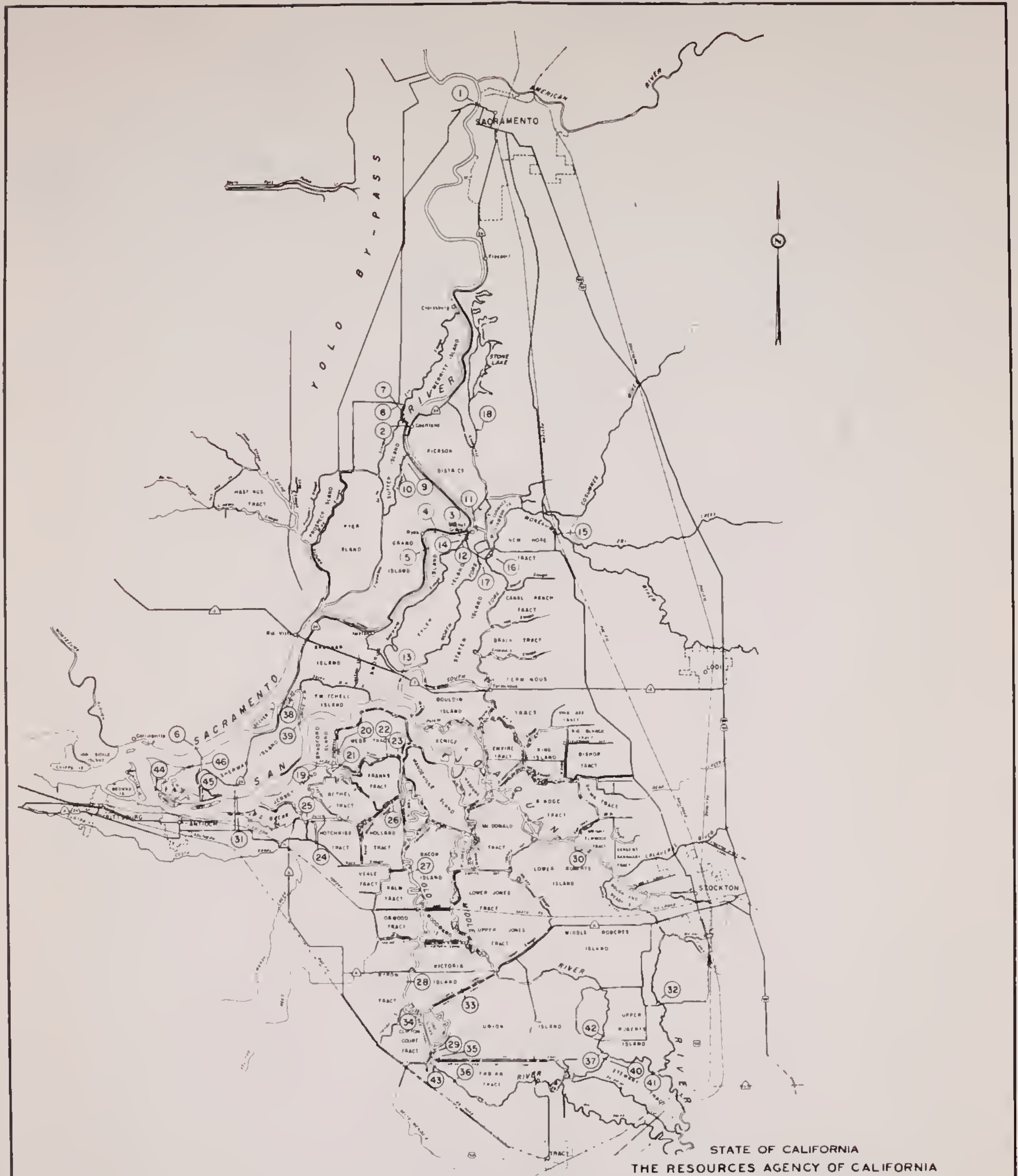
DELTA WATER FACILITIES

TIDAL PRISM VOLUMES
APRIL 1962



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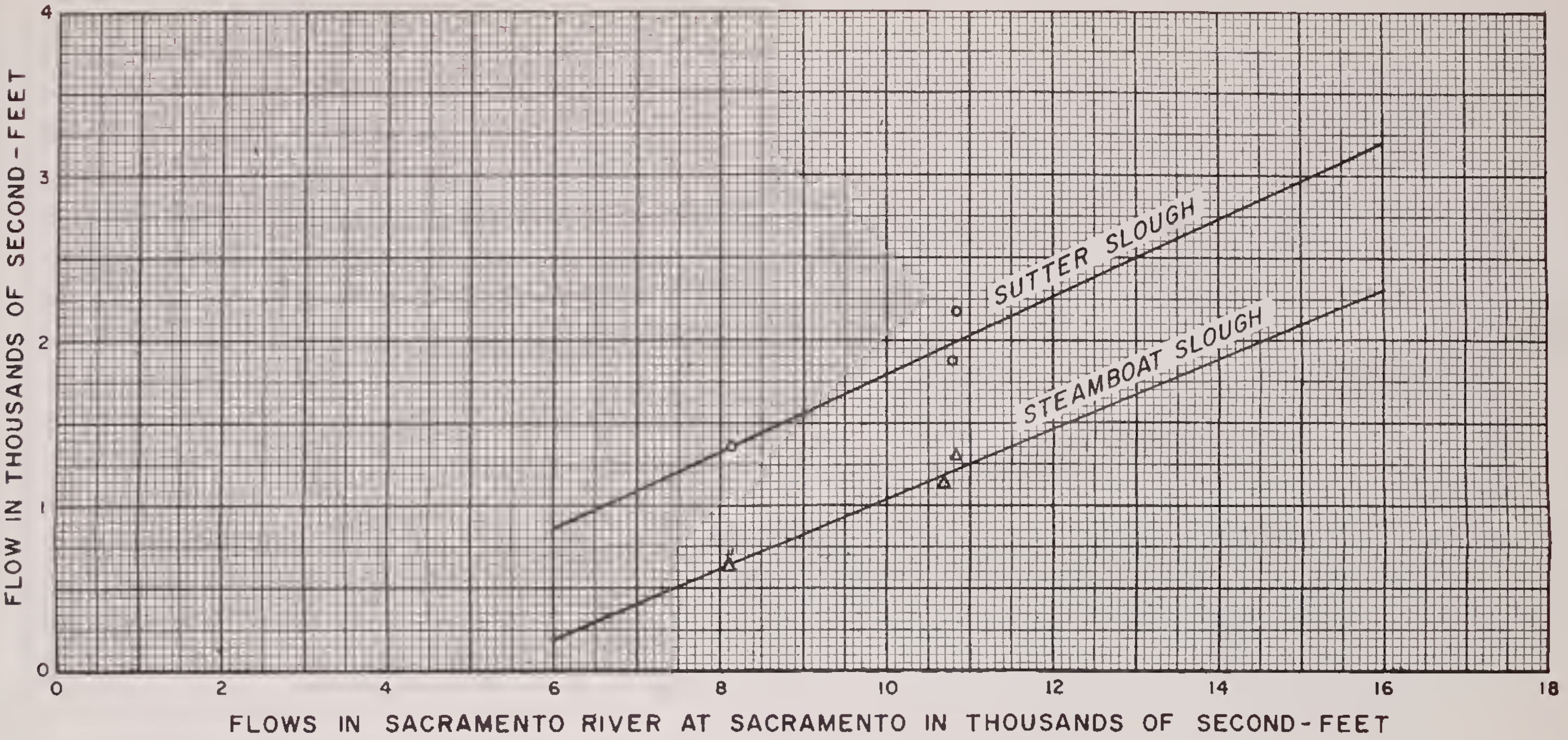
DELTA BRANCH

TIDAL FLOW MEASUREMENT LOCATIONS

APRIL 1962

SCALE OF MILES
2 0 2 4 6 8

PLATE 9



NOTE: Tidal flow measurements made with Delta Cross Channel gates open.

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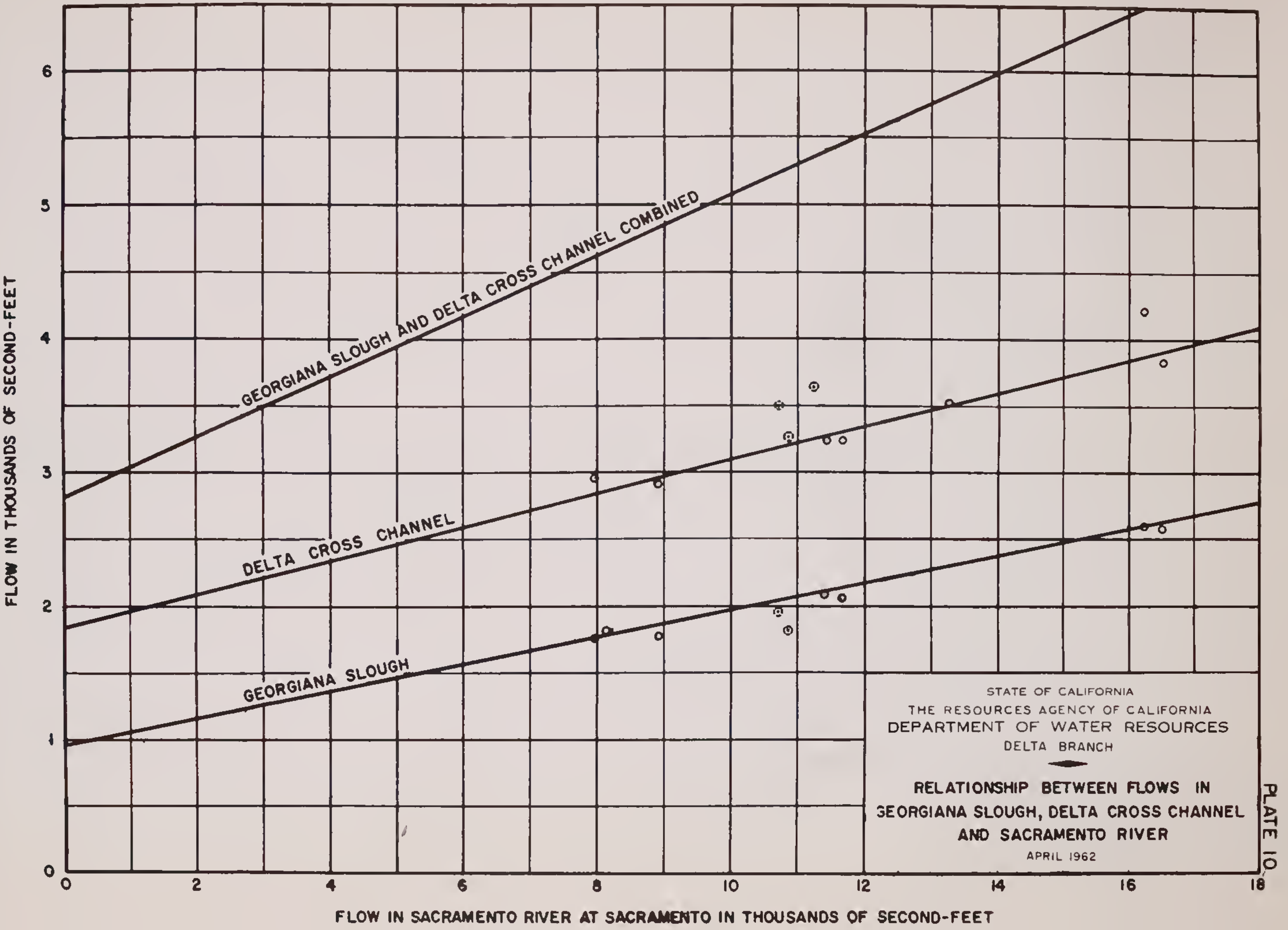
DELTA WATER FACILITIES

RELATIONSHIP BETWEEN FLOWS IN STEAMBOAT SLOUGH, SUTTER SLOUGH, AND SACRAMENTO RIVER

APRIL, 1962

PLATE 10



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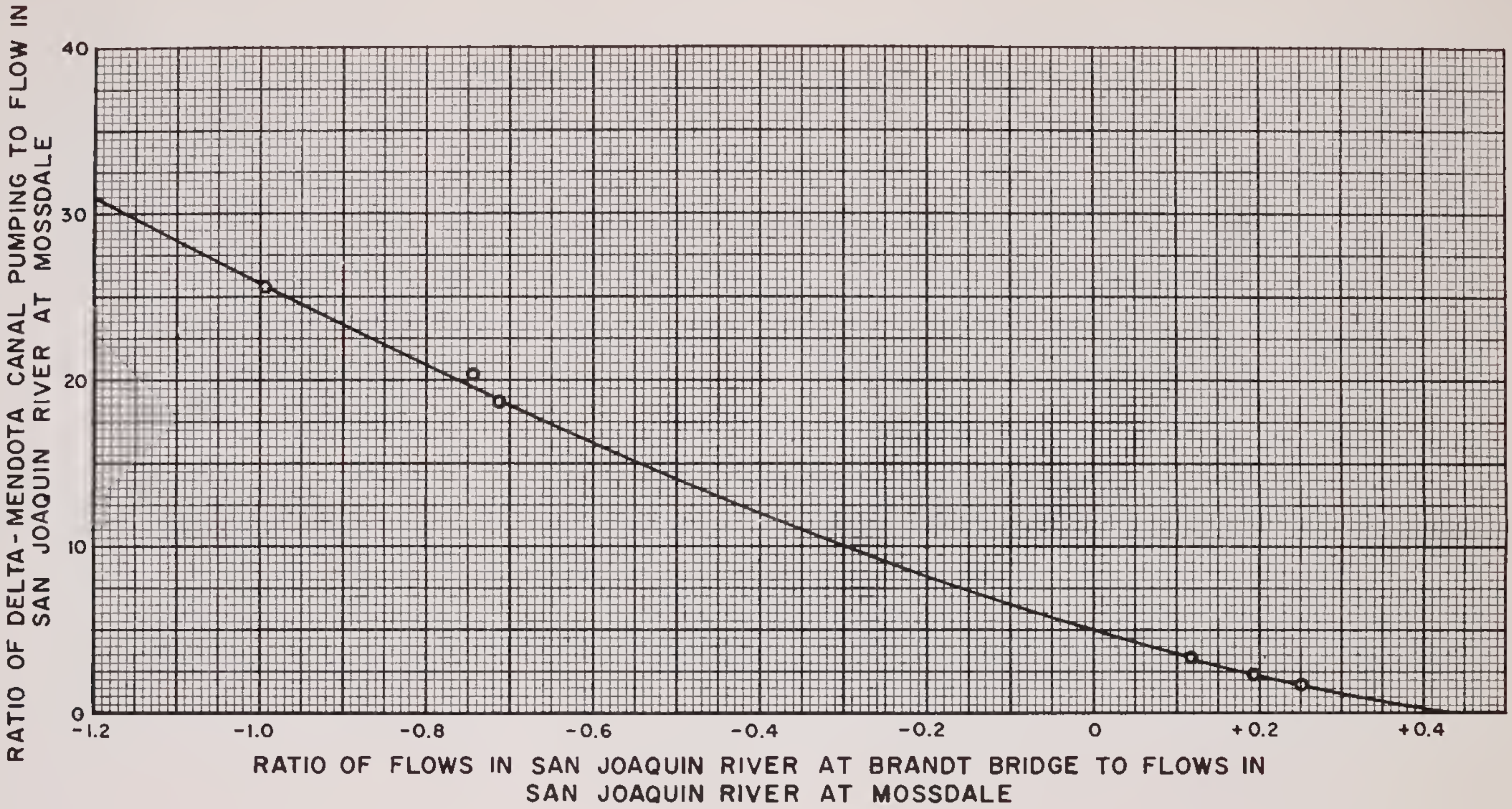
DEPARTMENT OF WATER RESOURCES
DELTA BRANCH

RELATIONSHIP BETWEEN FLOWS IN
GEORGIANA SLOUGH, DELTA CROSS CHANNEL
AND SACRAMENTO RIVER

APRIL 1962

PLATE II



NOTE: Flows in northwesterly direction in San Joaquin River at Brant Bridge positive and in opposite direction negative.

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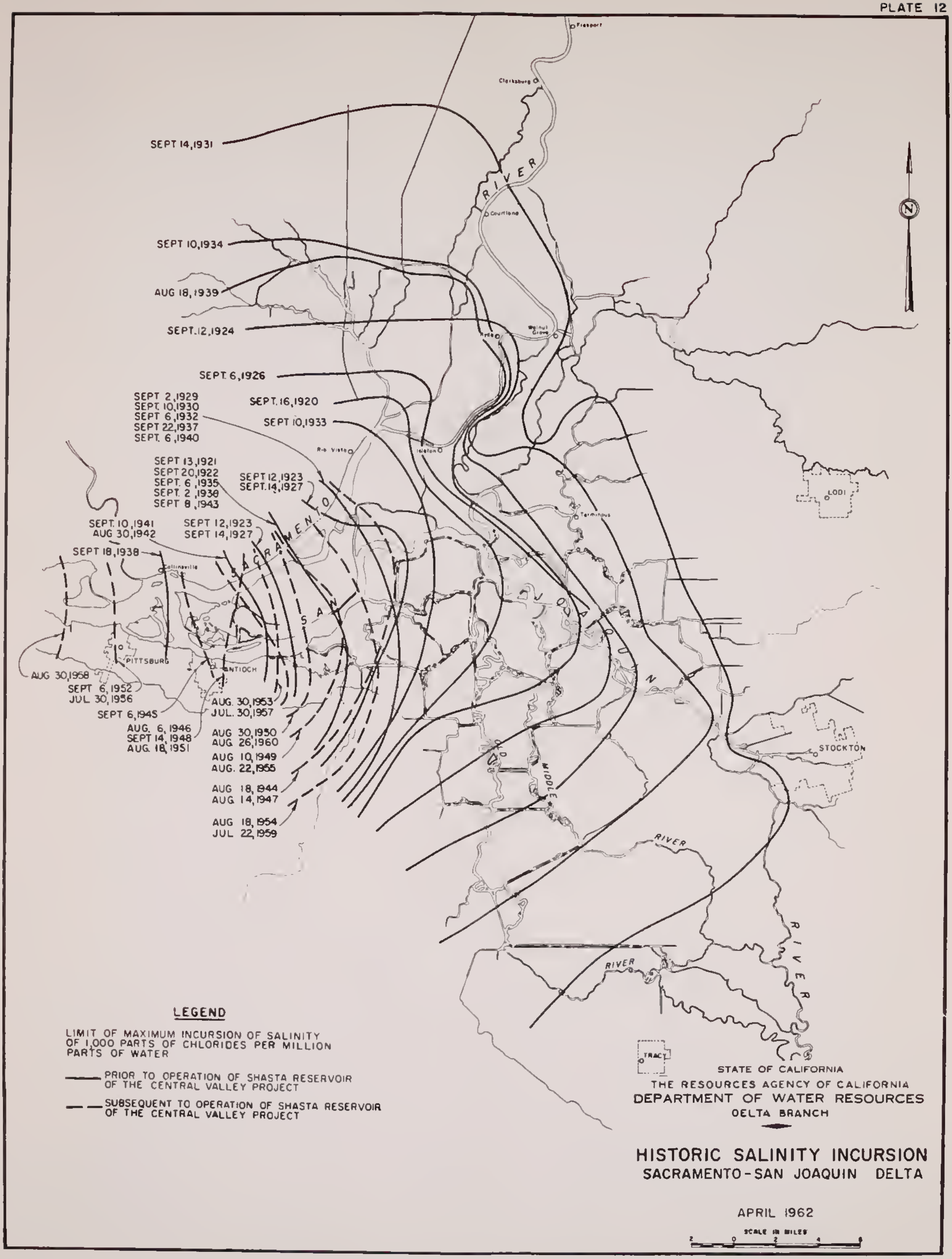
DELTA WATER FACILITIES

RATIO OF FLOW AT TWO LOCATIONS ON SAN JOAQUIN RIVER AS INFLUENCED BY DELTA-MENDOTA CANAL PUMPING

APRIL 1962



LEGEND

LIMIT OF MAXIMUM INCURSION OF SALINITY OF 1,000 PARTS OF CHLORIDES PER MILLION PARTS OF WATER

——— PRIOR TO OPERATION OF SHASTA RESERVOIR OF THE CENTRAL VALLEY PROJECT

— — SUBSEQUENT TO OPERATION OF SHASTA RESERVOIR OF THE CENTRAL VALLEY PROJECT

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HISTORIC SALINITY INCURSION
SACRAMENTO-SAN JOAQUIN DELTA

APRIL 1962

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DEPARTMENT OF WATER RESOURCES
DELTA BRANCH

SALINITY MEASURING LOCATIONS
SAN FRANCISCO BAY SYSTEM

APRIL 1962

SCALE IN MILES
2 0 2 4

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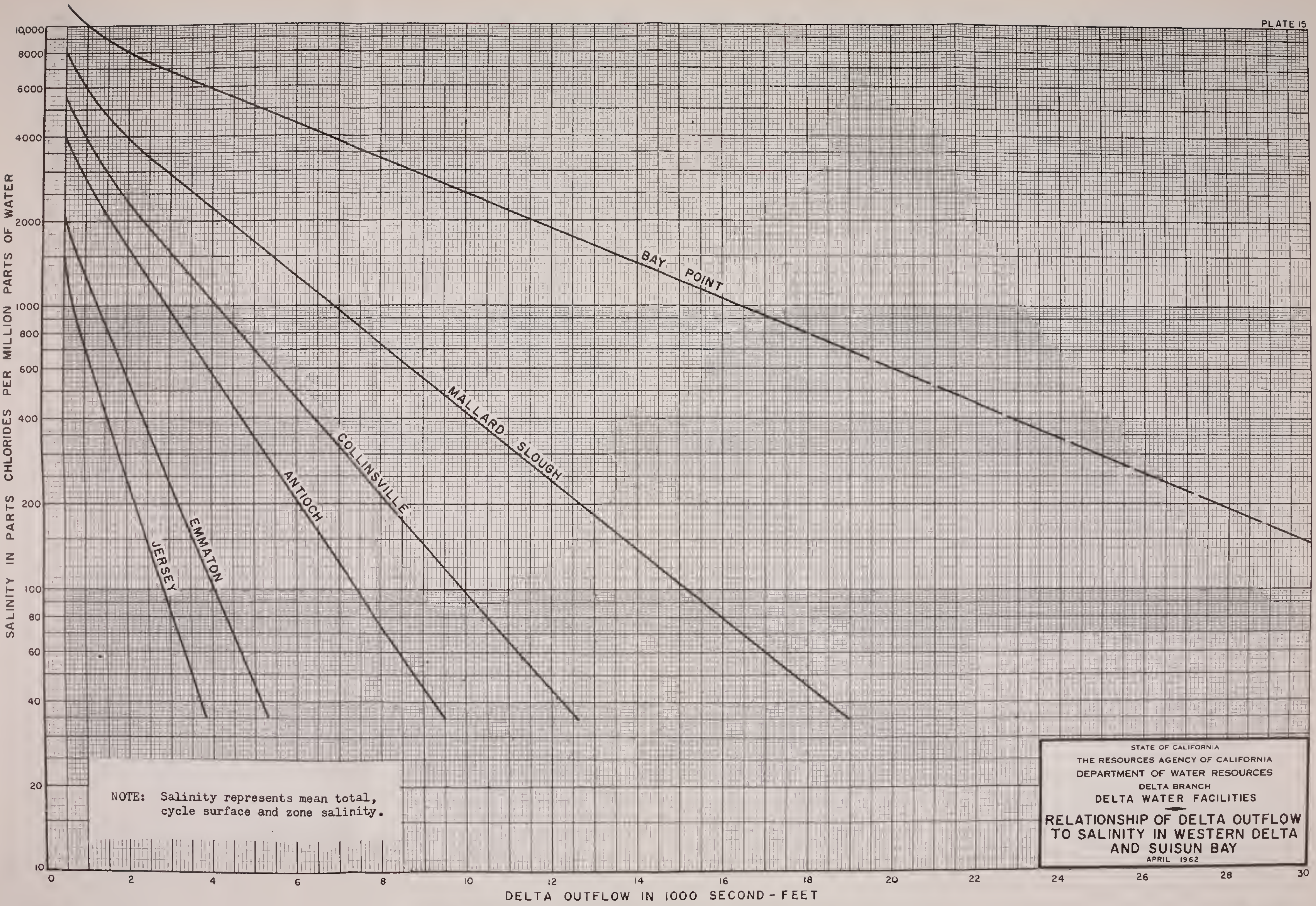
DELTA BRANCH

SALINITY MEASURING LOCATIONS
SACRAMENTO-SAN JOAQUIN DELTA

APRIL 1962

SCALE OF MILES
2 0 2 4 6 8



NOTE: Salinity represents mean total, cycle surface and zone salinity.

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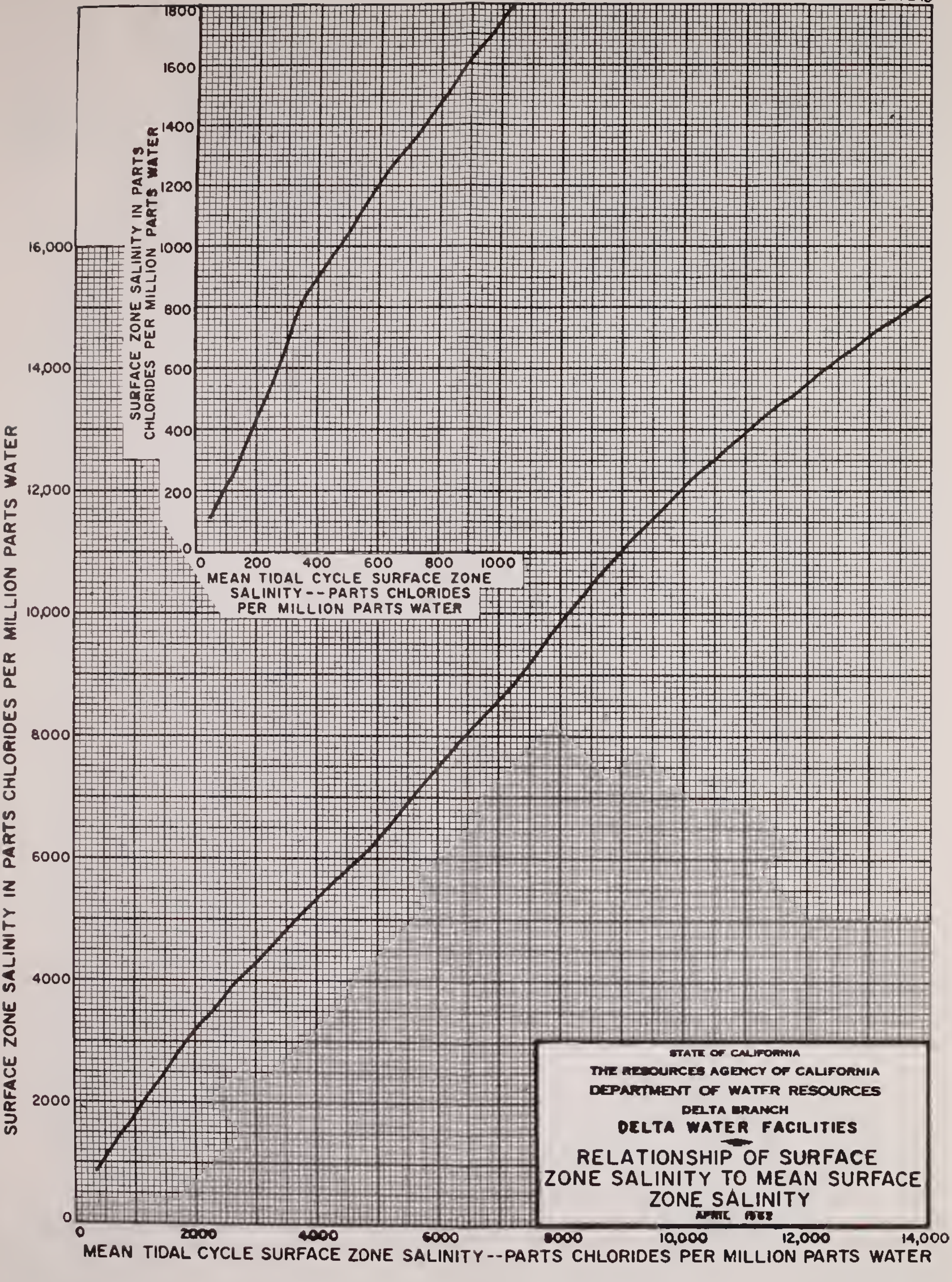
DELTA BRANCH
DELTA WATER FACILITIES

RELATIONSHIP OF DELTA OUTFLOW TO SALINITY IN WESTERN DELTA AND SUISUN BAY

APRIL 1962

PLATE 16



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DEPARTMENT OF WATER RESOURCES
DELTA BRANCH
DELTA WATER FACILITIES

RELATIONSHIP OF SURFACE ZONE SALINITY TO MEAN SURFACE ZONE SALINITY

APRIL 1962

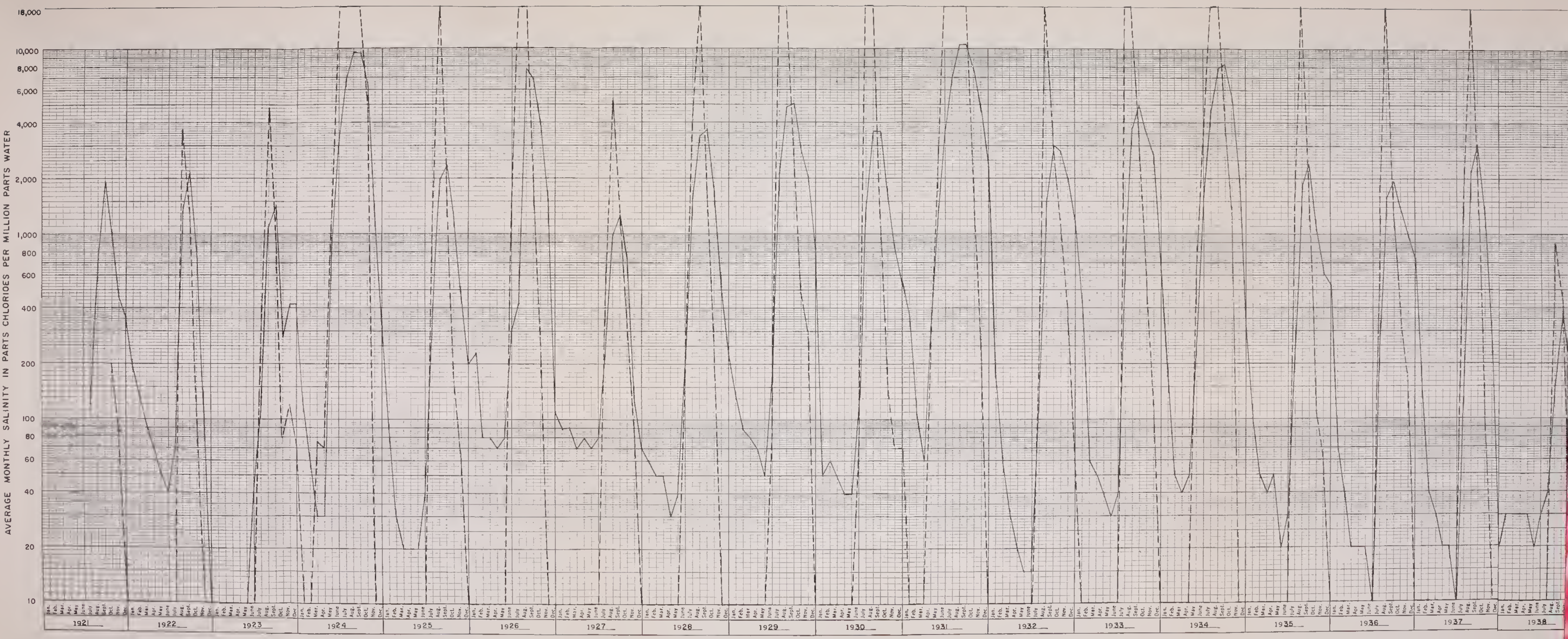
AVERAGE MONTHLY SALINITY IN PARTS CHLORIDES PER MILLION PARTS WATER
18,000
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
80
60
40
20
10
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938

PLATE 17

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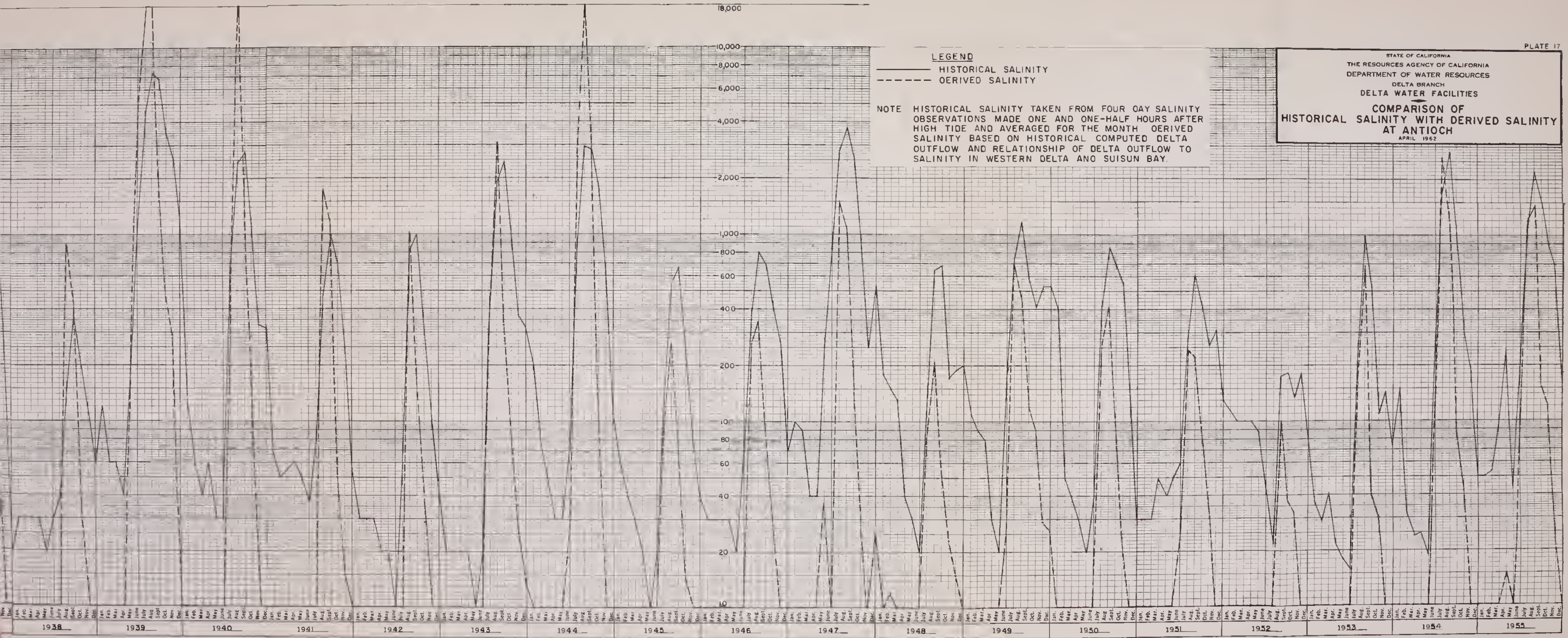
DEPARTMENT OF WATER RESOURCES
DELTA BRANCH
DELTA WATER FACILITIES

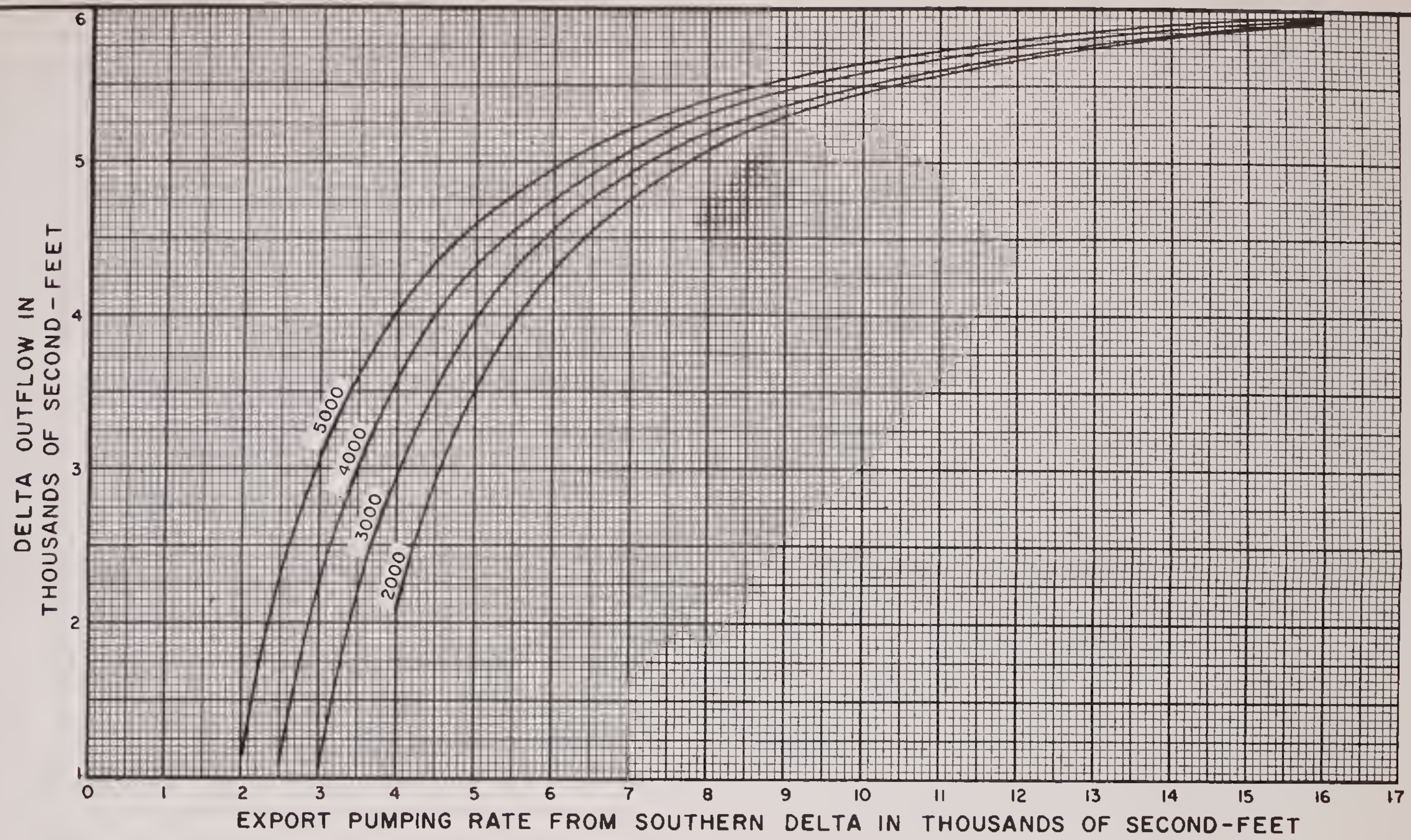
COMPARISON OF HISTORICAL SALINITY WITH DERIVED SALINITY AT ANTIOCH

APRIL 1962



NOTE HISTORICAL SALINITY TAKEN FROM FOUR DAY SALINITY OBSERVATIONS MADE ONE AND ONE-HALF HOURS AFTER HIGH TIDE AND AVERAGED FOR THE MONTH DERIVED SALINITY BASED ON HISTORICAL COMPUTED DELTA OUTFLOW AND RELATIONSHIP OF DELTA OUTFLOW TO SALINITY IN WESTERN DELTA AND SUISUN BAY.

PLATE 18



NOTE: Quality of water exported at one hundred parts chlorides per million parts water.
Export pumping from facilities near City of Tracy in southern Delta, both State and Federal.
Numbers along curves indicate consumptive use in Delta in second-feet.

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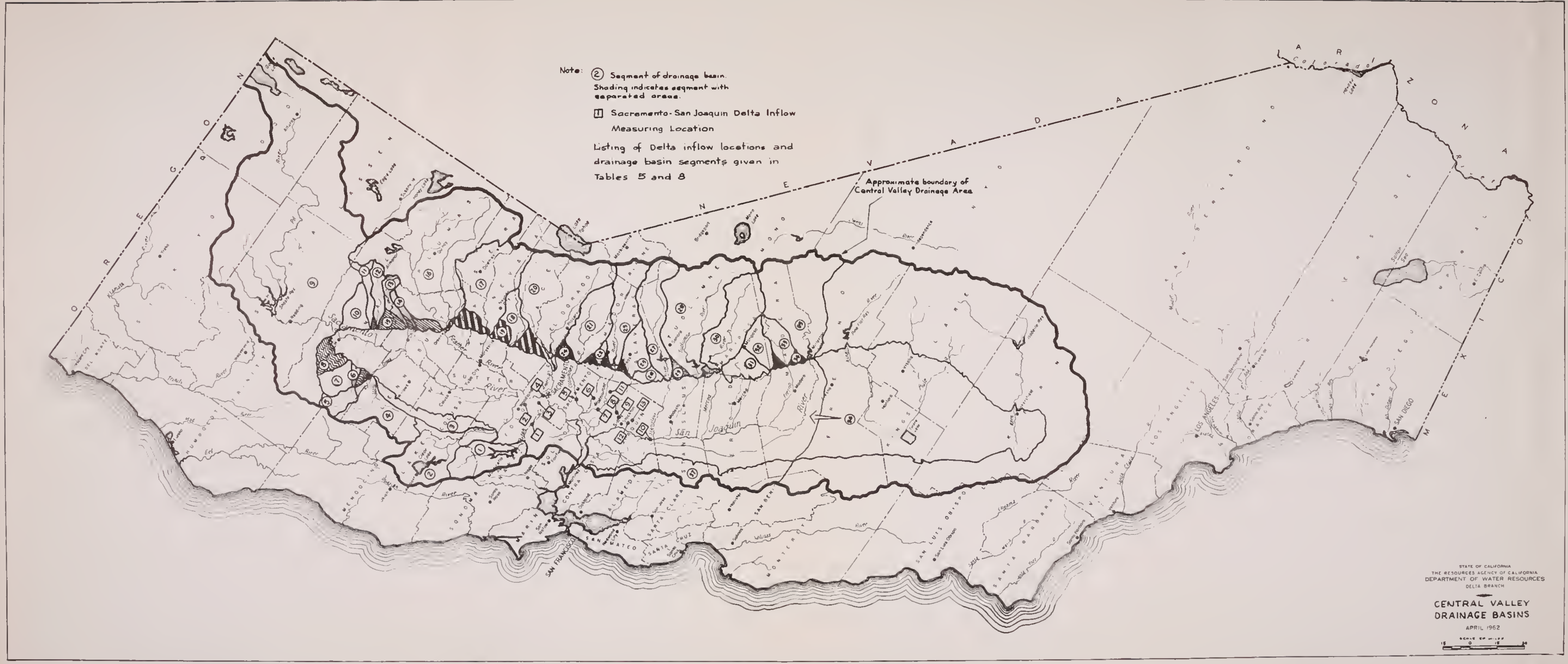
DELTA BRANCH
DELTA WATER FACILITIES

RELATIONSHIP OF DELTA OUTFLOW TO EXPORT PUMPING RATE

APRIL 1962



Note: ② Segment of drainage basin.
Shading indicates segment with separated areas.

1 Sacramento-San Joaquin Delta Inflow Measuring Location

Listing of Delta inflow locations and drainage basin segments given in Tables 5 and 8

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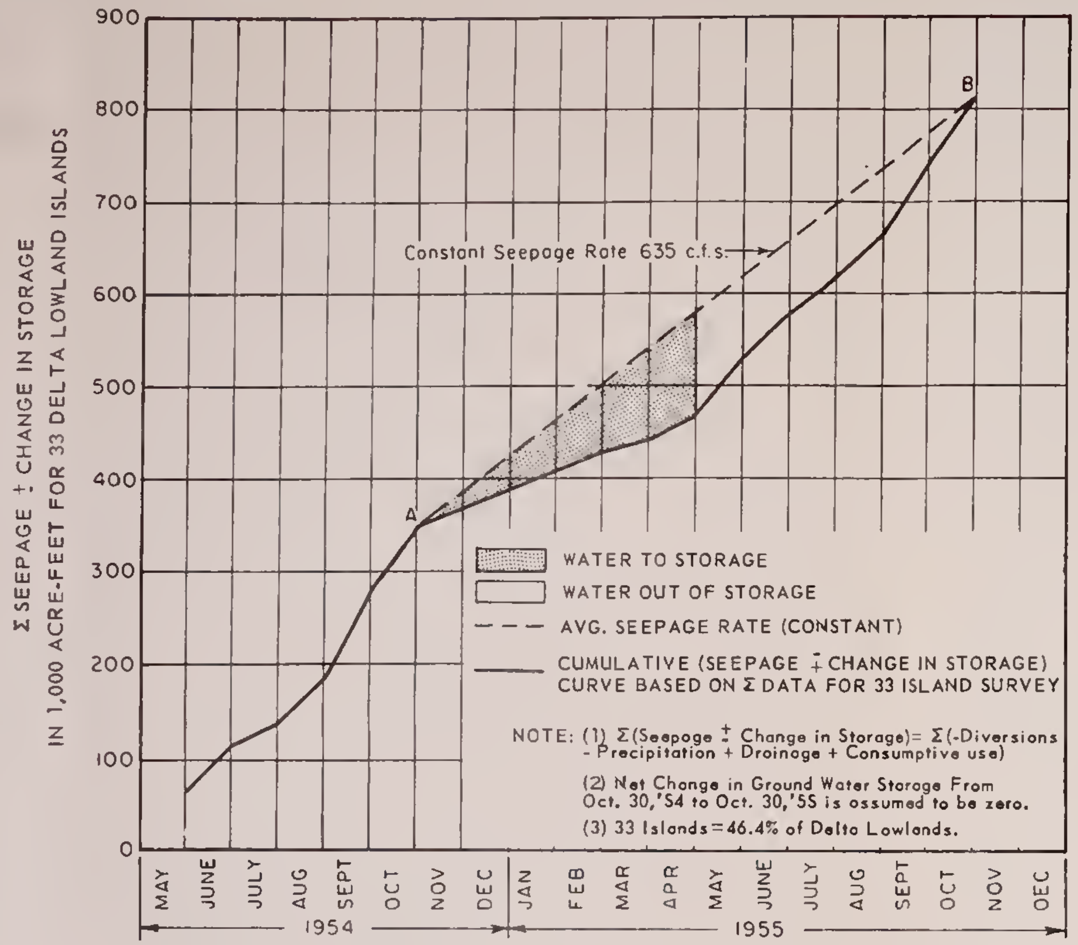
DELTA BRANCH

CENTRAL VALLEY DRAINAGE BASINS

APRIL 1962

SCALE OF MILES
15 0 15 30

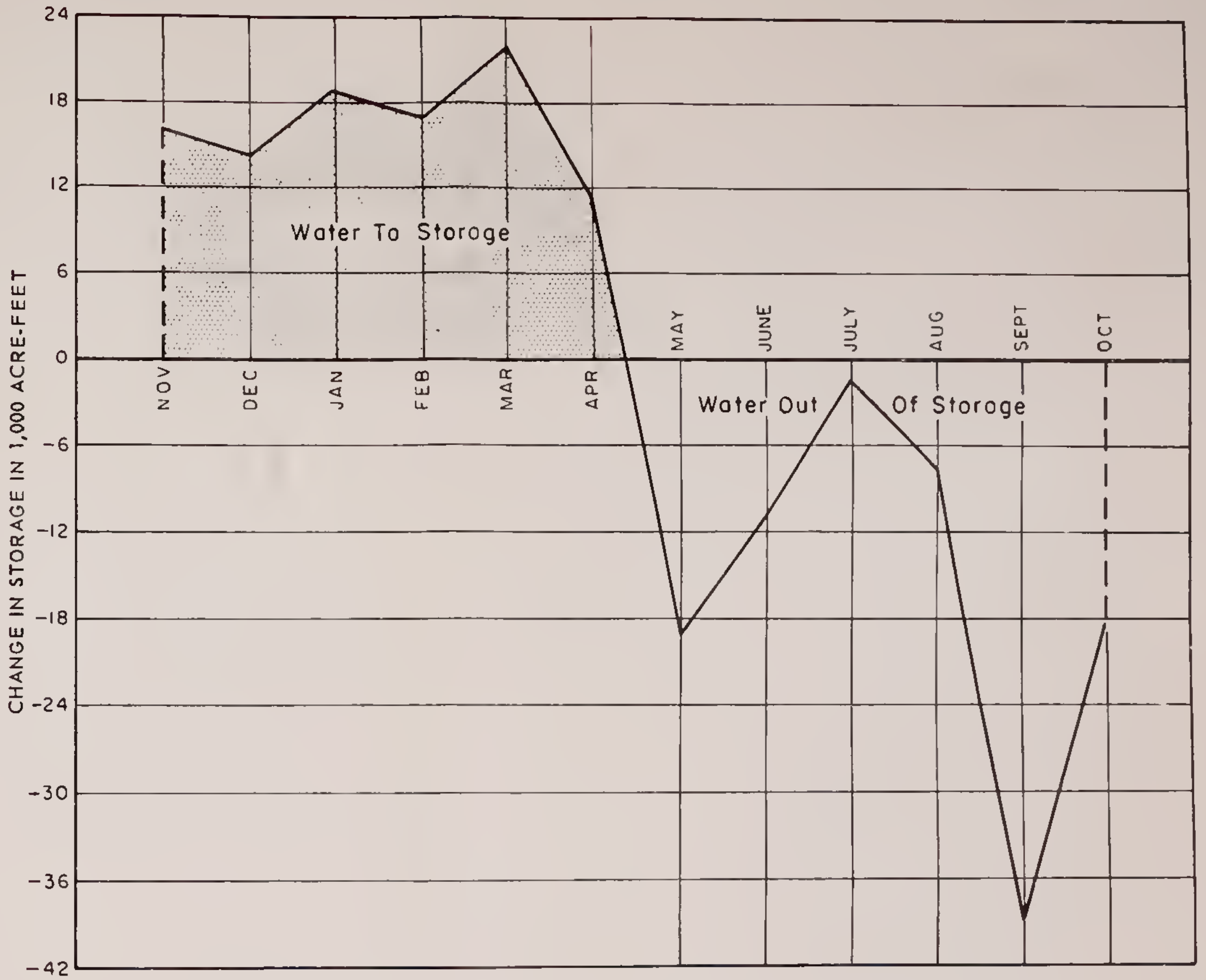


NOTE: (1) Σ(Seepage ± Change in Storage) = Σ(-Diversions - Precipitation + Drainage + Consumptive use)

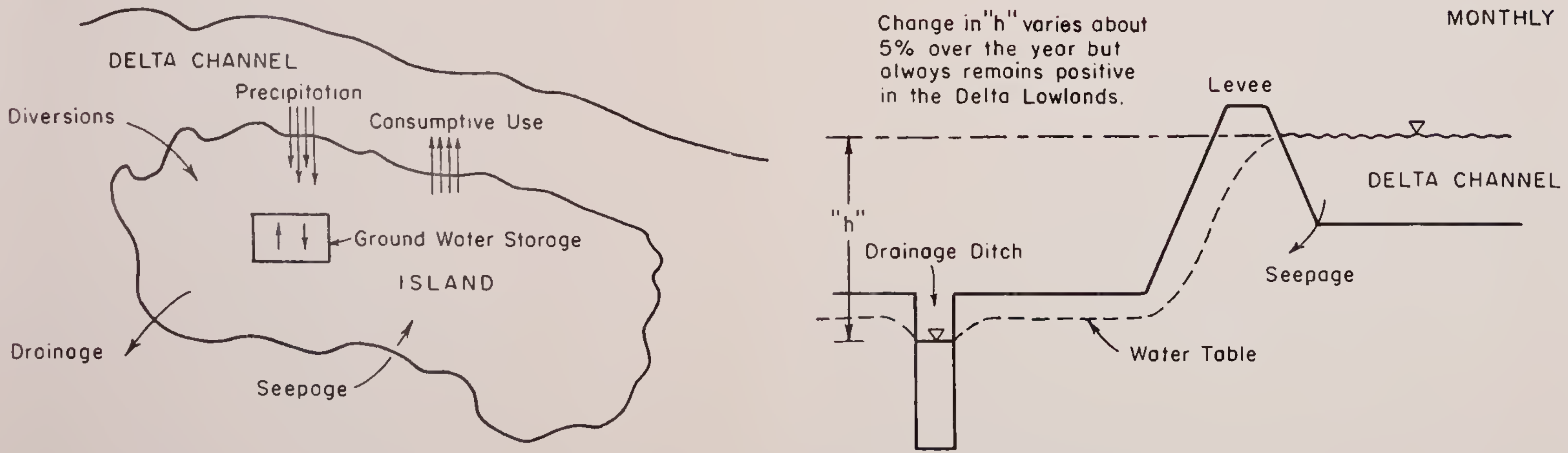
(2) Net Change in Ground Water Storage From Oct. 30,'54 to Oct. 30,'55 is assumed to be zero.

(3) 33 Islands = 46.4% of Delta Lowlands.

MASS DIAGRAM OF SEEPAGE AND CHANGE IN GROUND WATER STORAGE



MONTHLY CHANGE IN GROUND WATER STORAGE



Drainage + Consumptive Use = Precipitation + Diversions + Seepage ± Change In Ground Water Storage

SKETCH DEPICTING HYDROLOGIC EQUATION

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DELTA BRANCH
DELTA WATER FACILITIES

SEEPAGE OF WATER FROM CHANNELS
INTO DELTA LOWLANDS

APRIL 1962

PLATE 21

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DEPARTMENT OF WATER RESOURCES
DELTA BRANCH
DELTA WATER FACILITIES

OUTFLOW FROM DELTA
NATURAL
CONDITION OF DEVELOPMENT

APRIL 1962

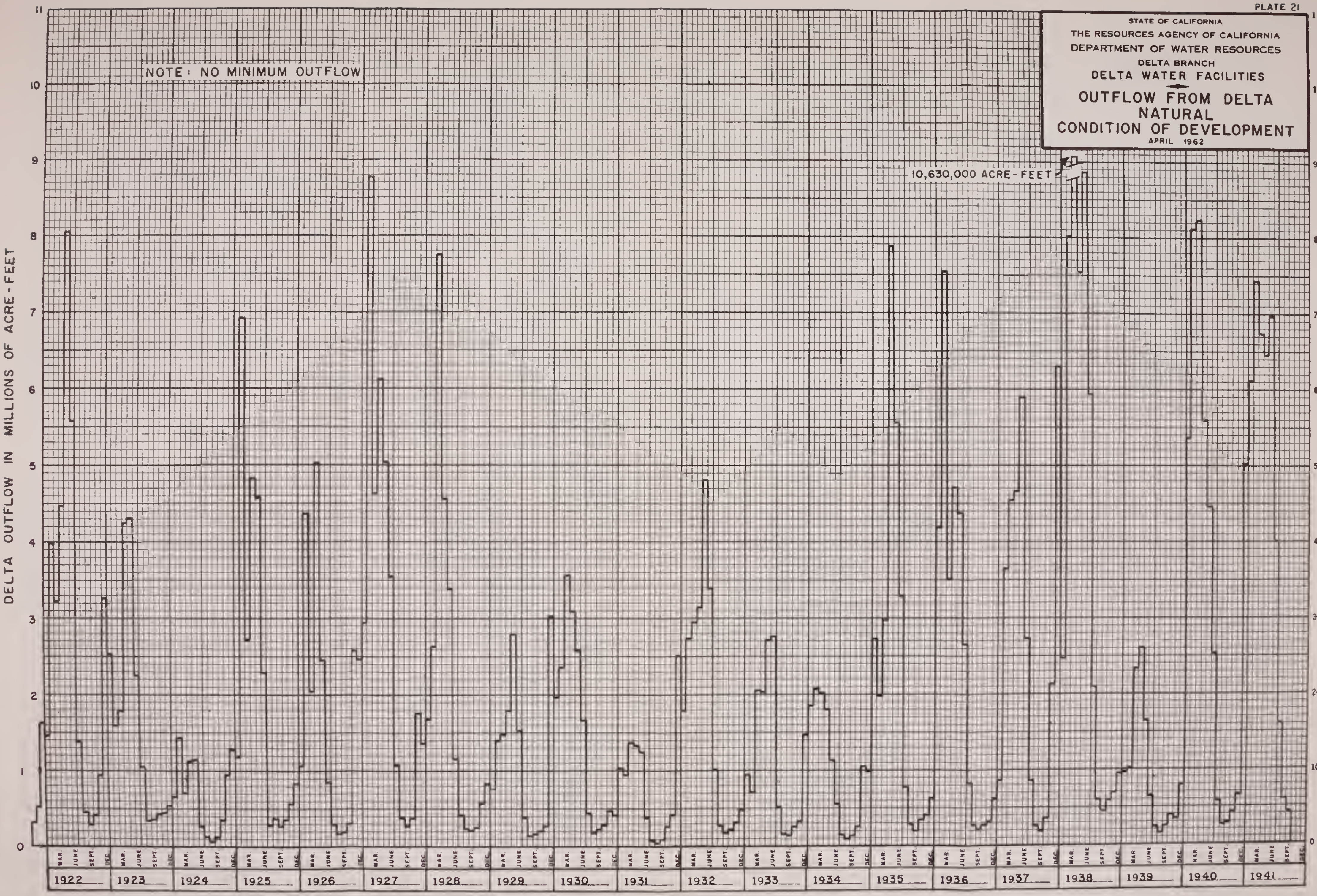
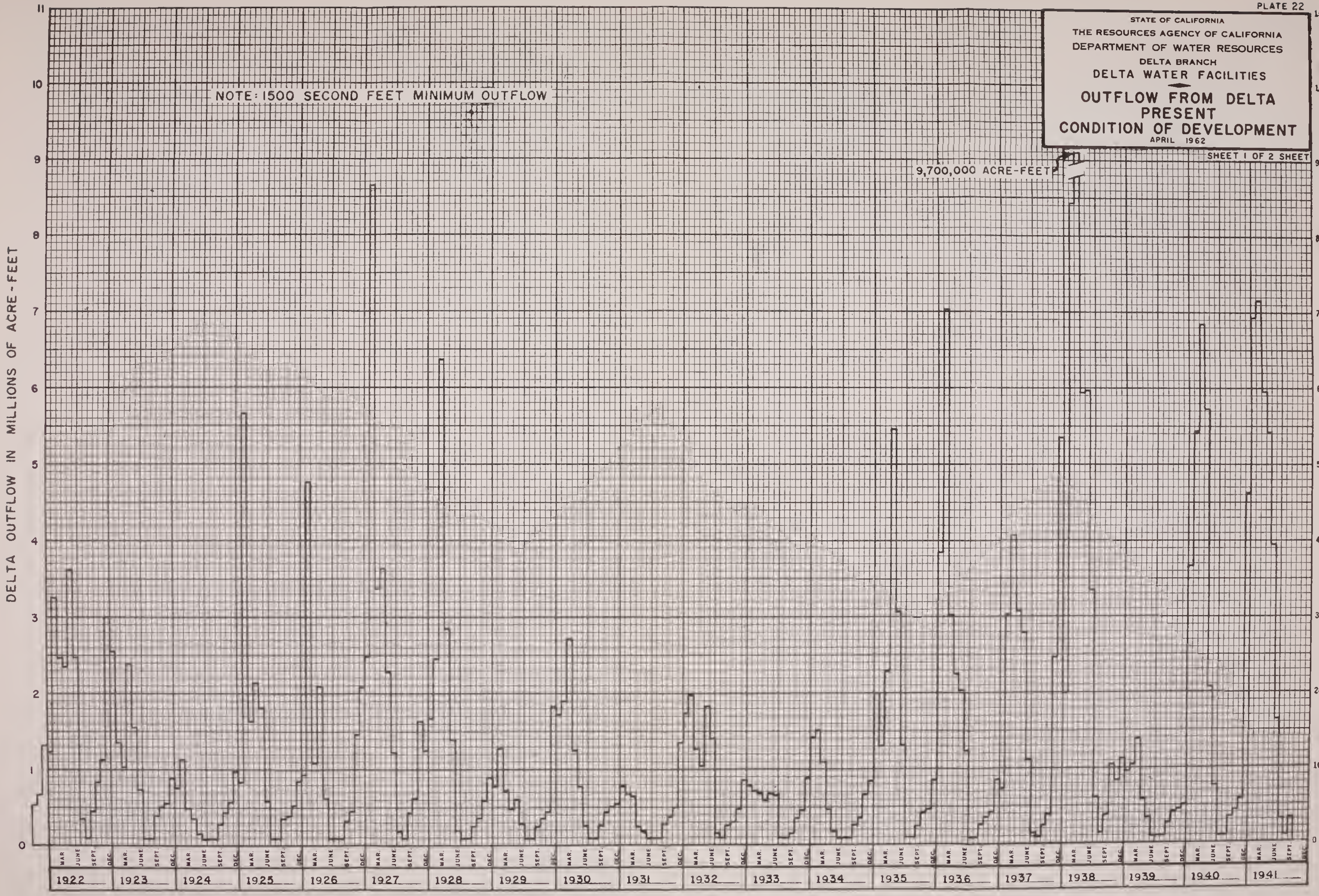


PLATE 22



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DELTA BRANCH
DELTA WATER FACILITIES

OUTFLOW FROM DELTA
PRESENT
CONDITION OF DEVELOPMENT

APRIL 1962

SHEET 1 OF 2 SHEET

NOTE: 1500 SECOND FEET MINIMUM OUTFLOW

9,700,000 ACRE-FEET

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OUTFLOW FROM DELTA PRESENT CONDITION OF DEVELOPMENT

APRIL 1962

SHEET 2 OF 2 SHEET

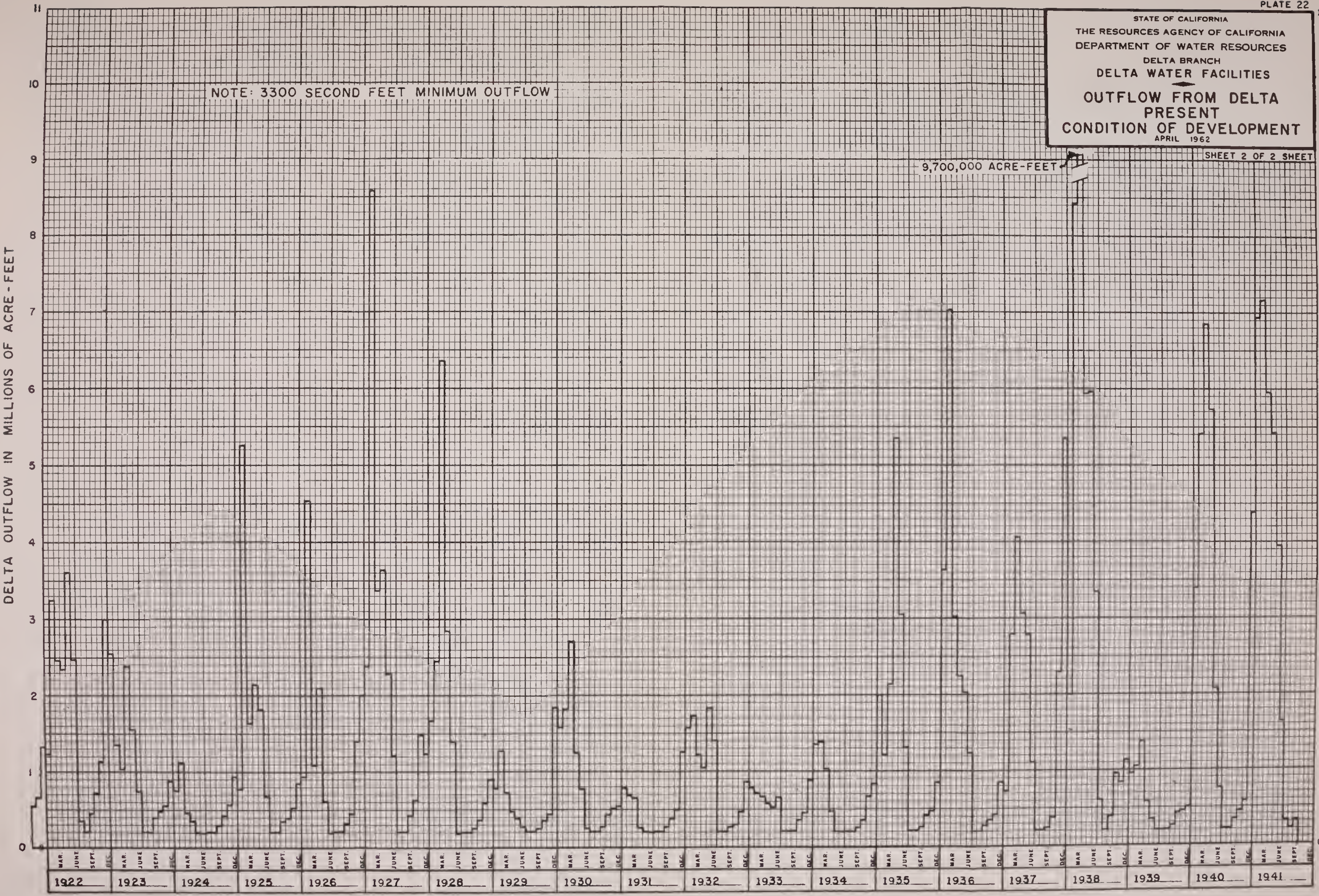

PLATE 23

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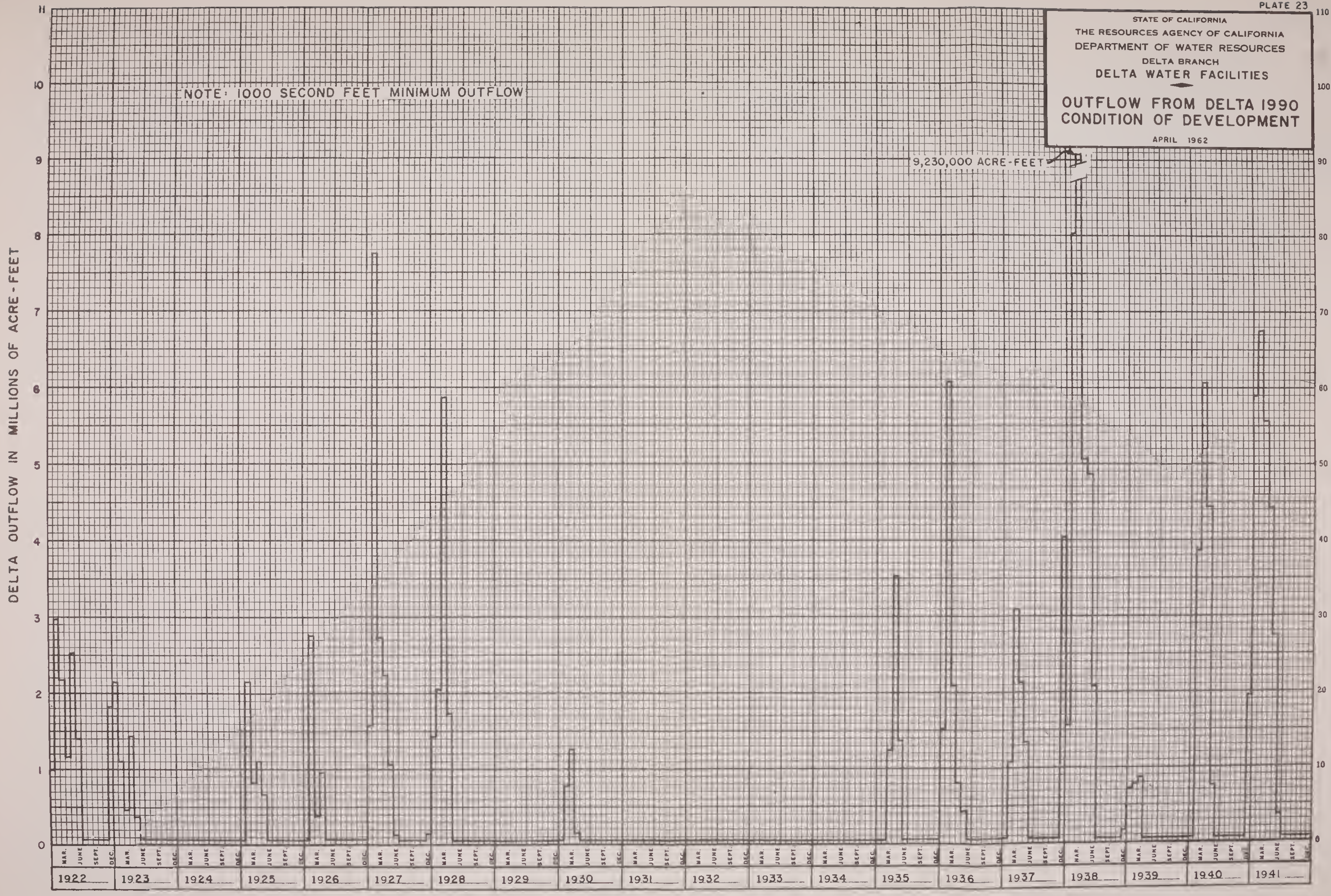
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DELTA BRANCH
DELTA WATER FACILITIES

OUTFLOW FROM DELTA 1990
CONDITION OF DEVELOPMENT

APRIL 1962



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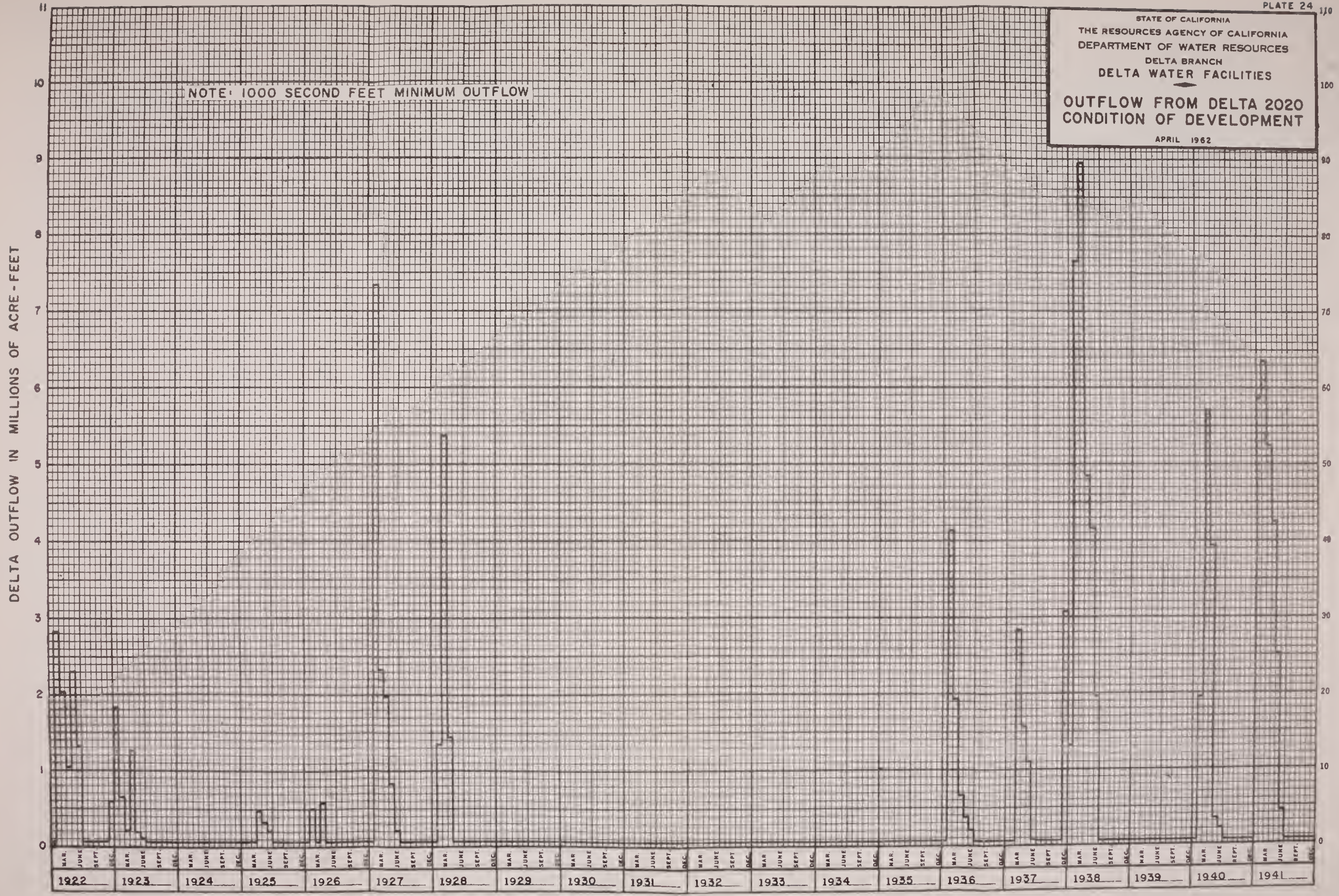
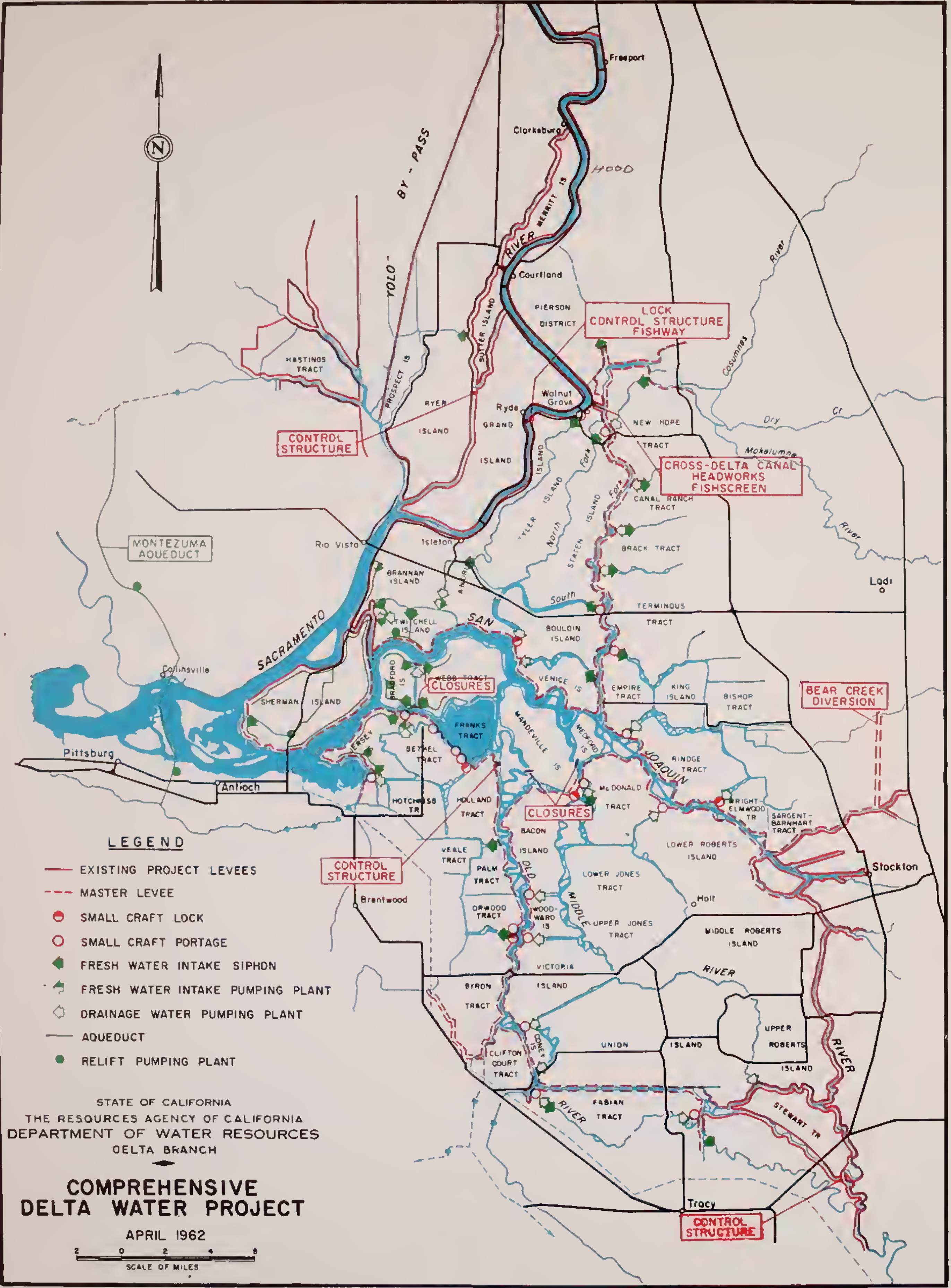
DELTA BRANCH
DELTA WATER FACILITIES

OUTFLOW FROM DELTA 2020 CONDITION OF DEVELOPMENT

APRIL 1962





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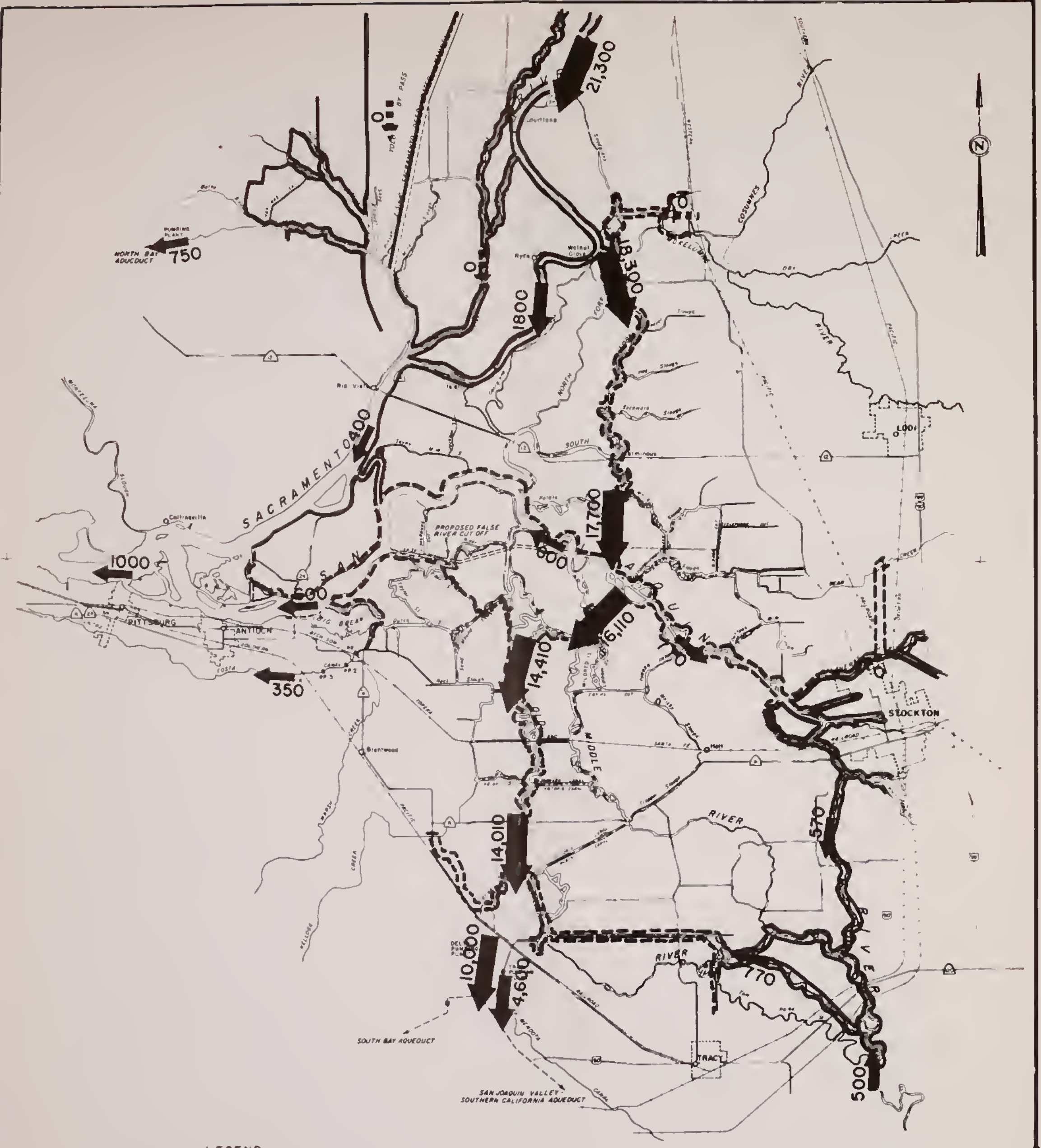
DELTA BRANCH

COMPREHENSIVE DELTA WATER PROJECT

APRIL 1962



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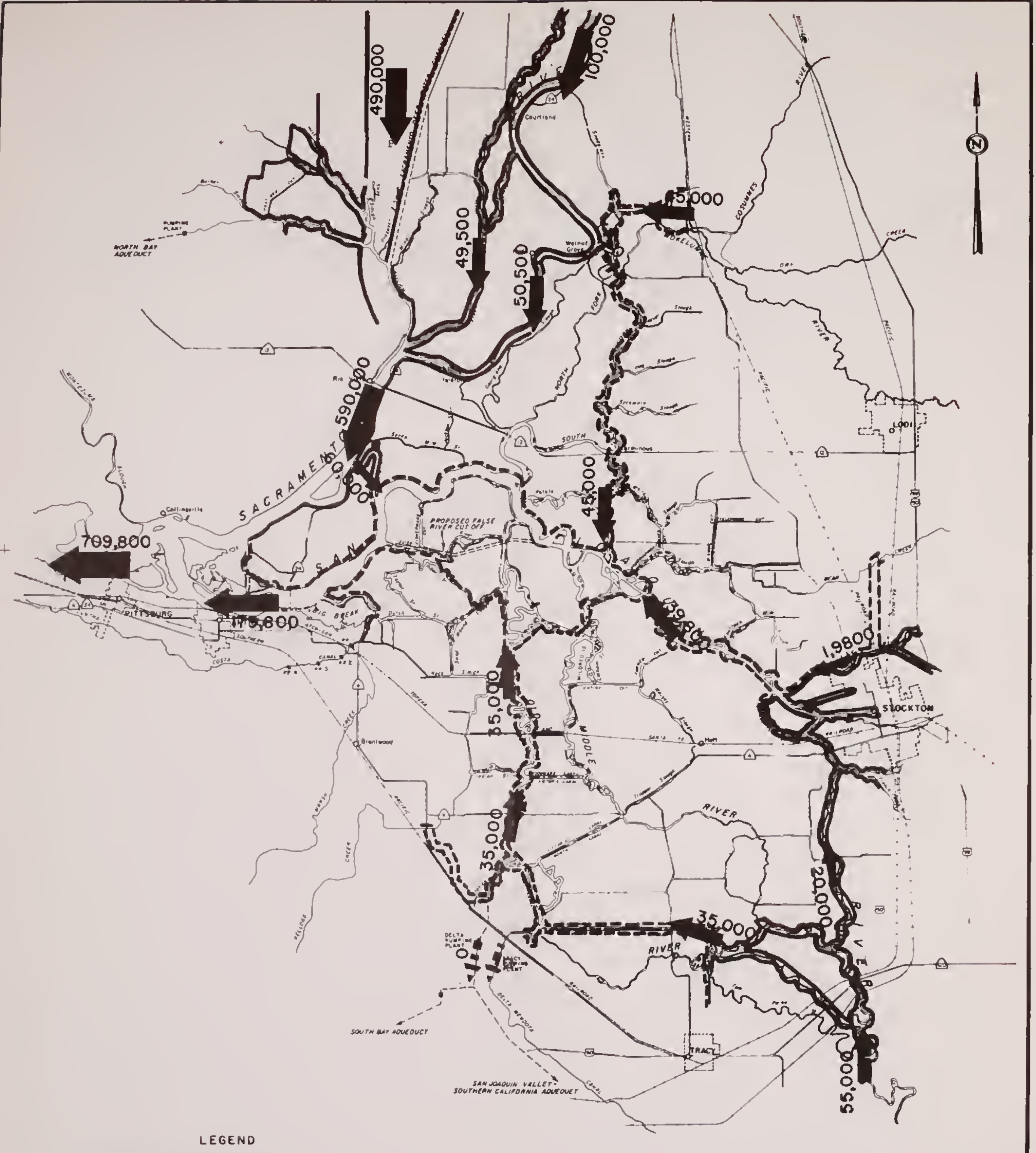
DELTA BRANCH

COMPREHENSIVE DELTA WATER PROJECT SUMMER FLOW DISTRIBUTION

APRIL 1962

SCALE IN MILES
2 0 2 4 6



LEGEND

5,000 ➞ FLOW IN CUBIC FEET PER SECOND

——— EXISTING LEVEES

– – – – – – PROJECT LEVEES

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THE RESOURCES AGENCY OF CALIFORNIA
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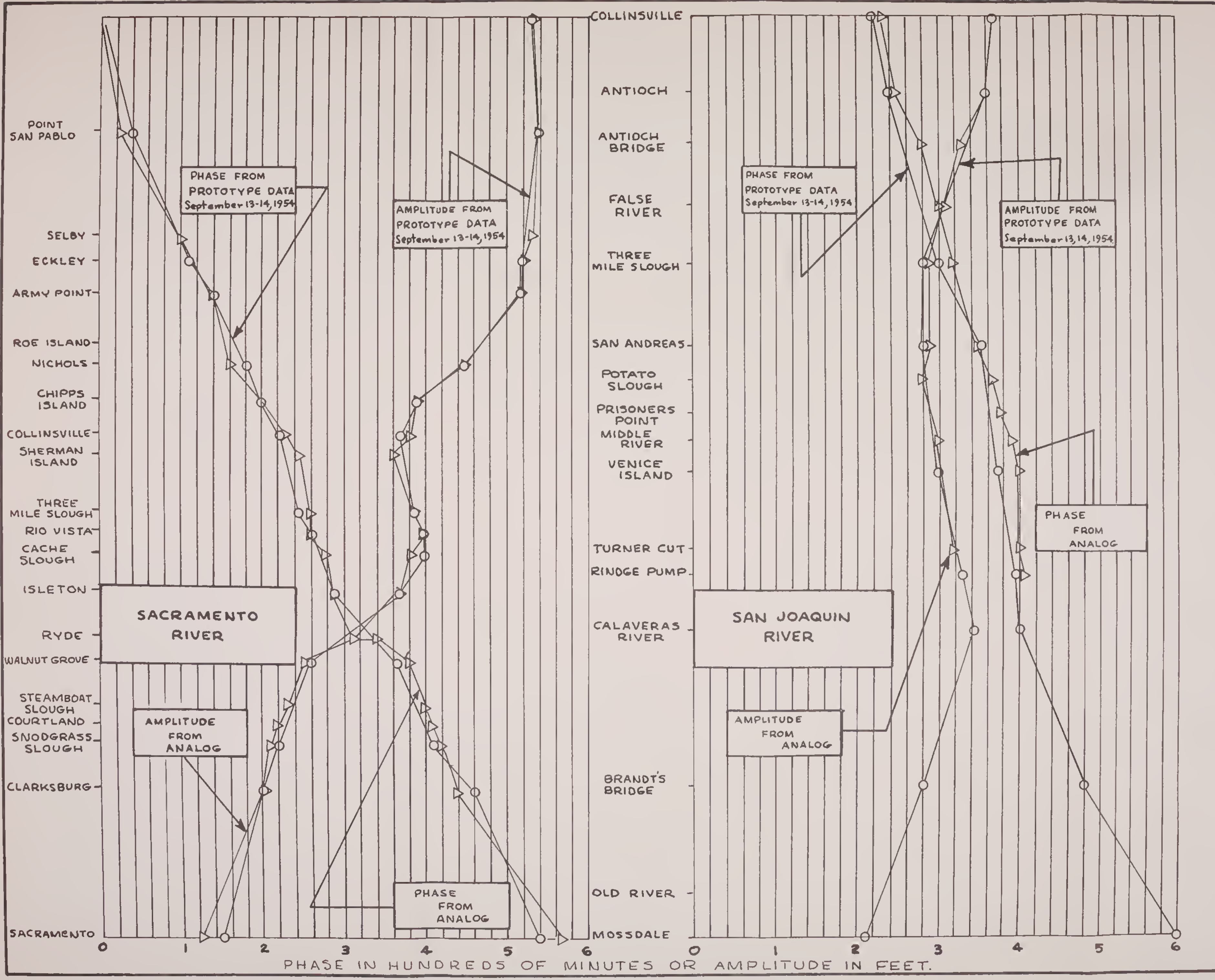
COMPREHENSIVE DELTA WATER PROJECT WINTER FLOW DISTRIBUTION

APRIL 1962

SCALE IN MILES
2 0 2 4 6



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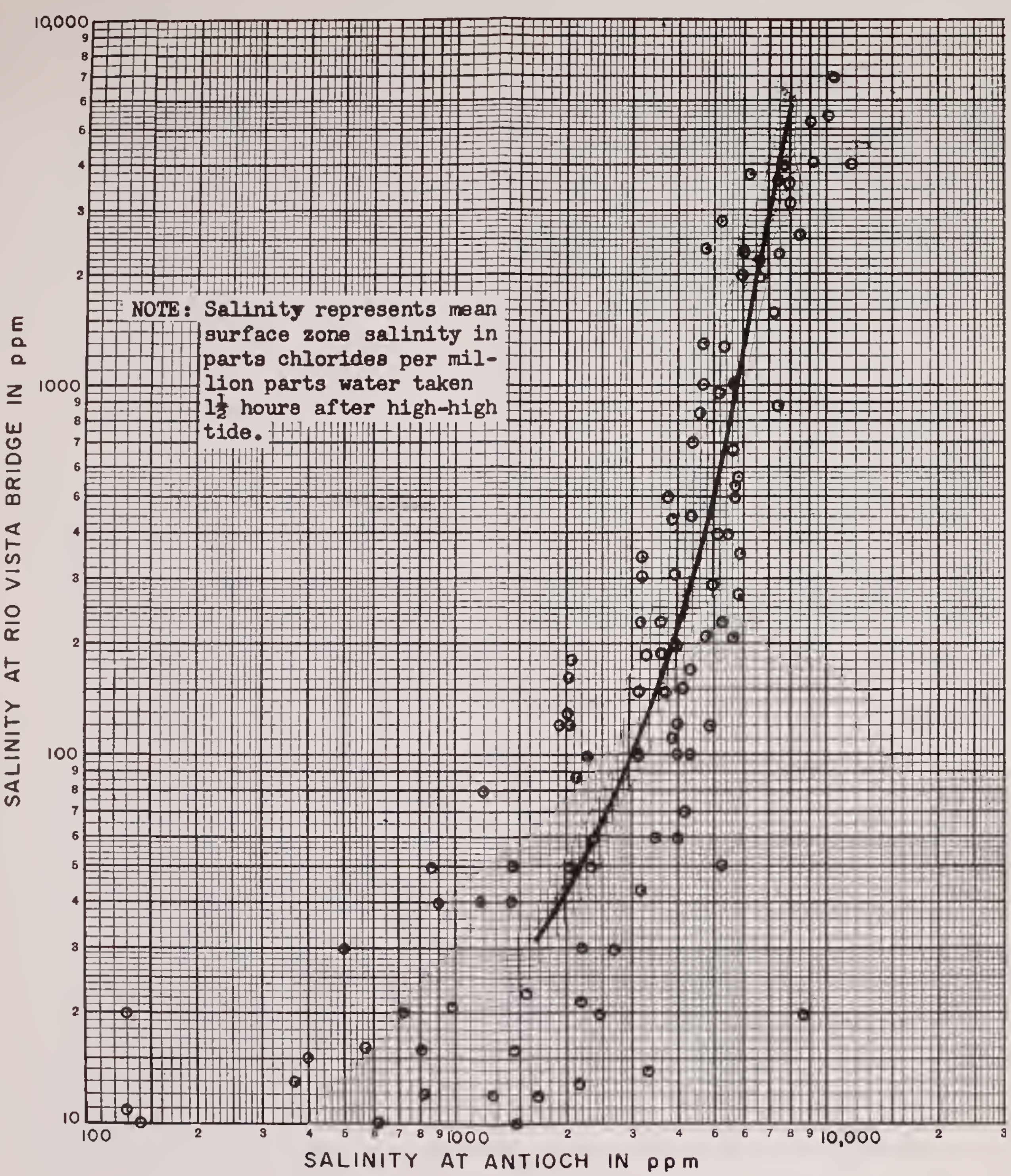
DELTA BRANCH
DELTA WATER FACILITIES

COMPARISON OF PROTOTYPE TIDAL PHASES AND AMPLITUDES WITH ANALOG MODEL TIDAL PHASES AND AMPLITUDES

APRIL 1962

PLATE 29



NOTE: Salinity represents mean surface zone salinity in parts chlorides per million parts water taken $1\frac{1}{2}$ hours after high-high tide.

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DELTA BRANCH
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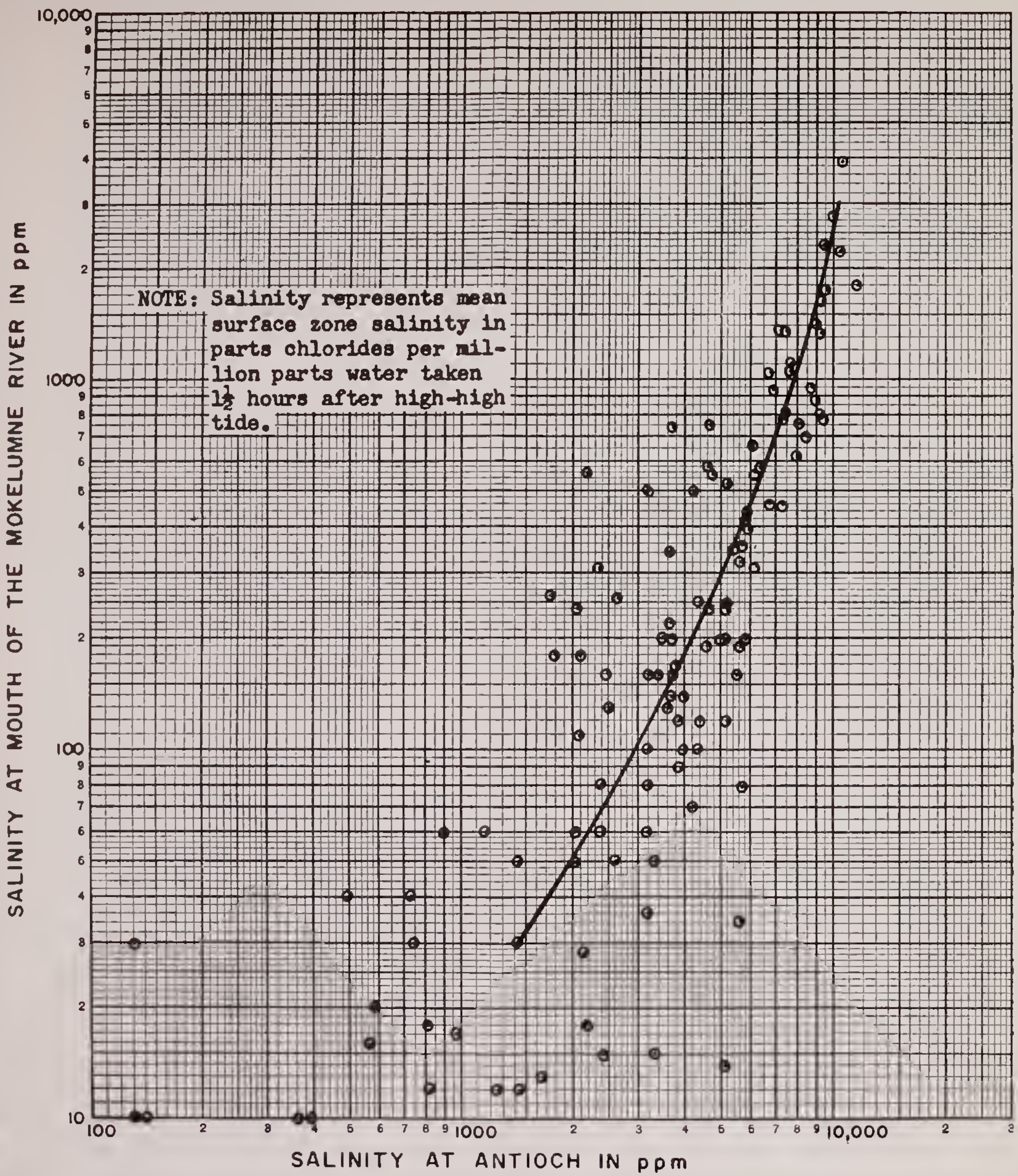
RELATIONSHIP OF SALINITY AT ANTIOCH TO SALINITY AT RIO VISTA BRIDGE

APRIL 1962

PLATE 30



NOTE: Salinity represents mean surface zone salinity in parts chlorides per million parts water taken $1\frac{1}{2}$ hours after high-high tide.

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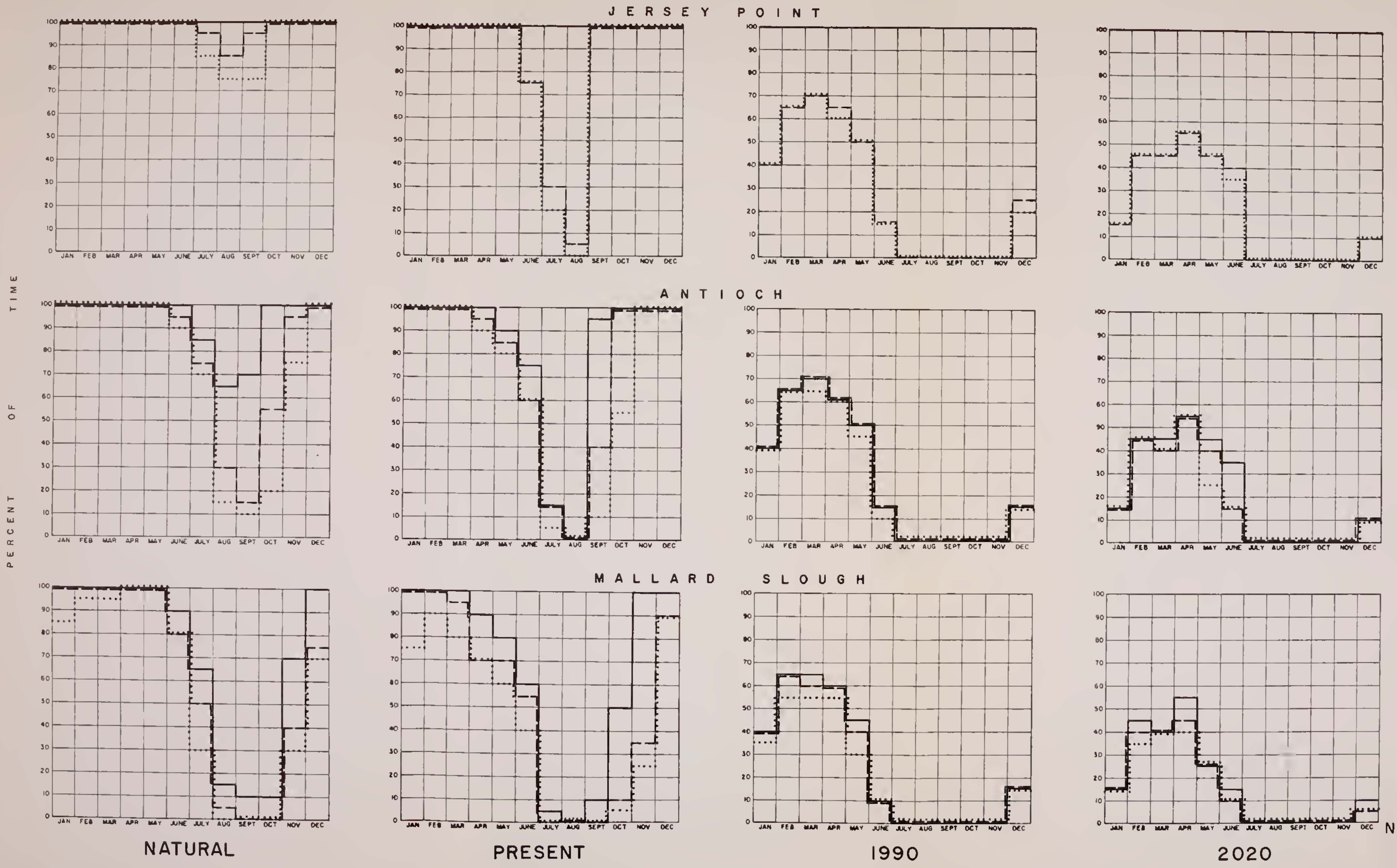
DELTA WATER FACILITIES

RELATIONSHIP OF SALINITY AT ANTIOCH TO SALINITY AT MOUTH OF MOKELUMNE RIVER

APRIL 1962



LEGEND

- ······· AVERAGE MONTHLY SALINITY LESS THAN 150 PPM
- — — — AVERAGE MONTHLY SALINITY LESS THAN 350 PPM
- ——— AVERAGE MONTHLY SALINITY LESS THAN 1000 PPM

SALINITY REPRESENTS MEAN TIDAL CYCLE SURFACE ZONE SALINITY EXPRESSED AS PARTS CHLORIDES PER MILLION PARTS WATER BY WEIGHT (PPM)

SALINITY BASED UPON ESTIMATED OUTFLOWS FROM THE SACRAMENTO-SAN JOAQUIN DELTA WITH 1922-41 WATER SUPPLY CONDITIONS, FOR THE FOLLOWING CONDITIONS OF DEVELOPMENT IN THE CENTRAL VALLEY:

NATURAL	BEFORE ANY SIGNIFICANT DEVELOPMENT
PRESENT	WITH EXISTING CONDITIONS OF UPSTREAM DEVELOPMENT AND OPERATION OF THE CENTRAL VALLEY PROJECT WITH IMPORTS OF WATER FROM THE TRINITY RIVER AND WITH A MINIMUM OUTFLOW OF 1,500 SECOND-FEET
1990:	WITH 1990 CONDITIONS OF UPSTREAM DEVELOPMENT, OPERATION OF THE CENTRAL VALLEY PROJECT, FEATHER RIVER PROJECT, DELTA DIVERSION PROJECT, DELTA WATER PROJECT AND IMPORTS OF WATER FROM THE NORTH COAST AND WITH A MINIMUM OUTFLOW OF 1,000 SECOND-FEET
2020:	WITH 2020 CONDITIONS OF UPSTREAM DEVELOPMENT AND OPERATION OF THE SAME PROJECTS AS LISTED FOR 1990 PLUS ADDITIONAL IMPORTS OF WATER FROM THE NORTH COAST AND WITH A MINIMUM OUTFLOW OF 1,000 SECOND-FEET

STATE OF CALIFORNIA
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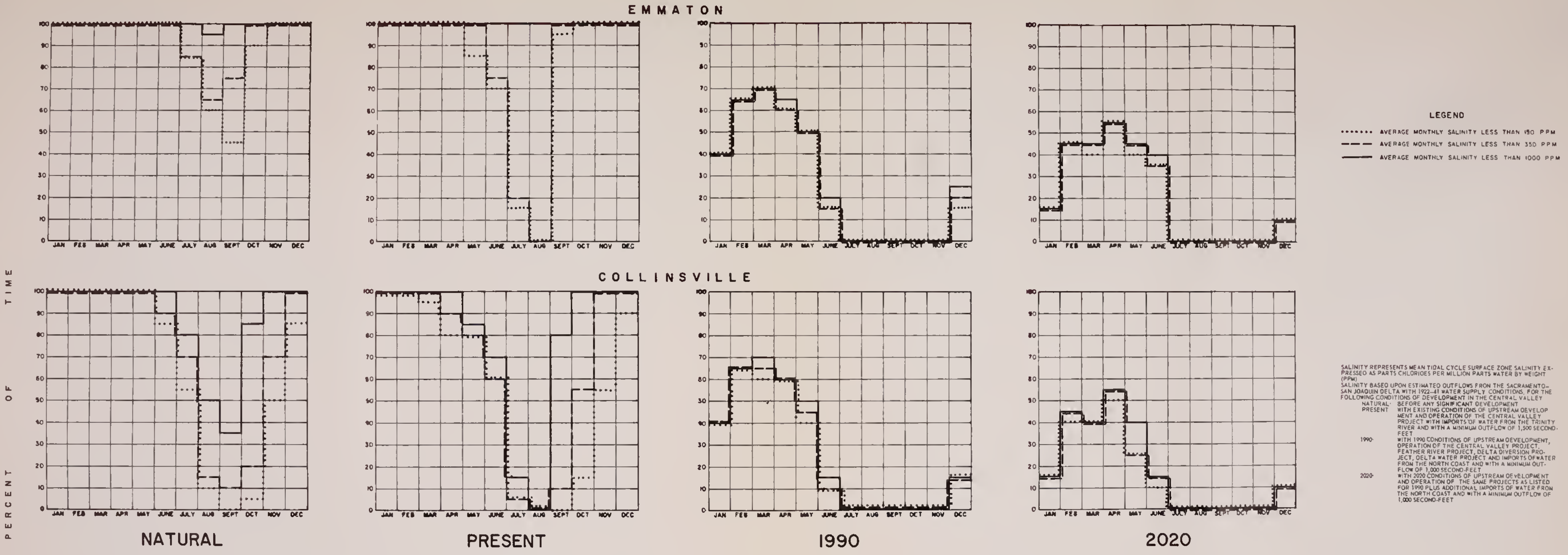
DELTA BRANCH

NATURAL, PRESENT AND FUTURE SALINITY CONDITIONS IN WESTERN SACRAMENTO-SAN JOAQUIN DELTA

APRIL 1962



SALINITY REPRESENTS MEAN TIDAL CYCLE SURFACE ZONE SALINITY EXPRESSED AS PARTS CHLORIDES PER MILLION PARTS WATER BY WEIGHT (PPM)

SALINITY BASED UPON ESTIMATED OUTFLOWS FROM THE SACRAMENTO-SAN JOAQUIN DELTA WITH 1922—41 WATER SUPPLY CONDITIONS, FOR THE FOLLOWING CONDITIONS OF DEVELOPMENT IN THE CENTRAL VALLEY

NATURAL·	BEFORE ANY SIGNIFICANT DEVELOPMENT
PRESENT	WITH EXISTING CONDITIONS OF UPSTREAM DEVELOPMENT AND OPERATION OF THE CENTRAL VALLEY PROJECT WITH IMPORTS OF WATER FROM THE TRINITY RIVER AND WITH A MINIMUM OUTFLOW OF 1,500 SECOND-FEET
1990·	WITH 1990 CONDITIONS OF UPSTREAM DEVELOPMENT, OPERATION OF THE CENTRAL VALLEY PROJECT, FEATHER RIVER PROJECT, DELTA DIVERSION PROJECT, DELTA WATER PROJECT AND IMPORTS OF WATER FROM THE NORTH COAST AND WITH A MINIMUM OUTFLOW OF 1,000 SECOND-FEET
2020·	WITH 2020 CONDITIONS OF UPSTREAM DEVELOPMENT AND OPERATION OF THE SAME PROJECTS AS LISTED FOR 1990 PLUS ADDITIONAL IMPORTS OF WATER FROM THE NORTH COAST AND WITH A MINIMUM OUTFLOW OF 1,000 SECOND-FEET

STATE OF CALIFORNIA
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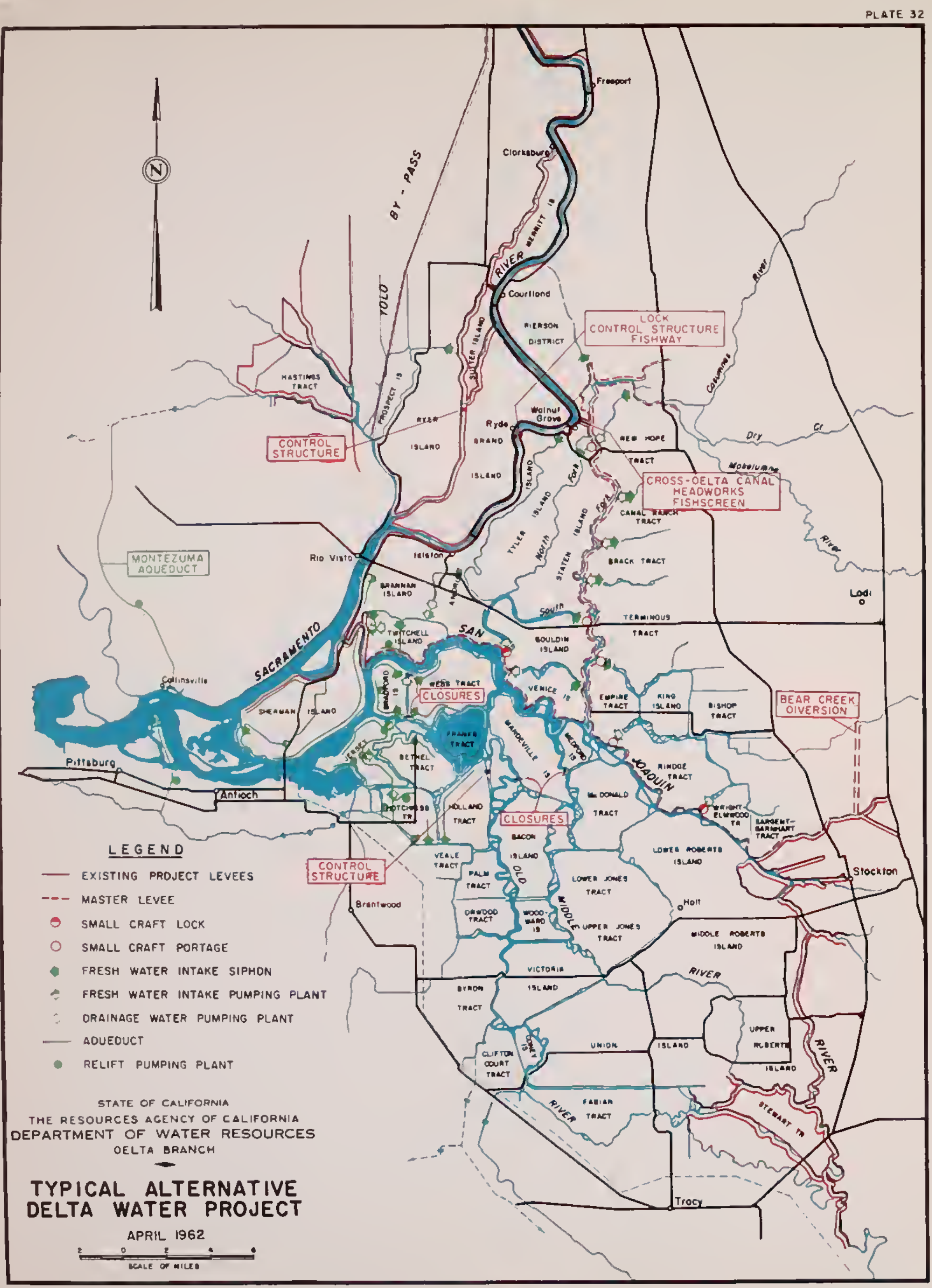
DELTA BRANCH

NATURAL, PRESENT AND FUTURE SALINITY CONDITIONS IN WESTERN SACRAMENTO-SAN JOAQUIN DELTA

APRIL 1962

SHEET 2 OF 2 SHEETS



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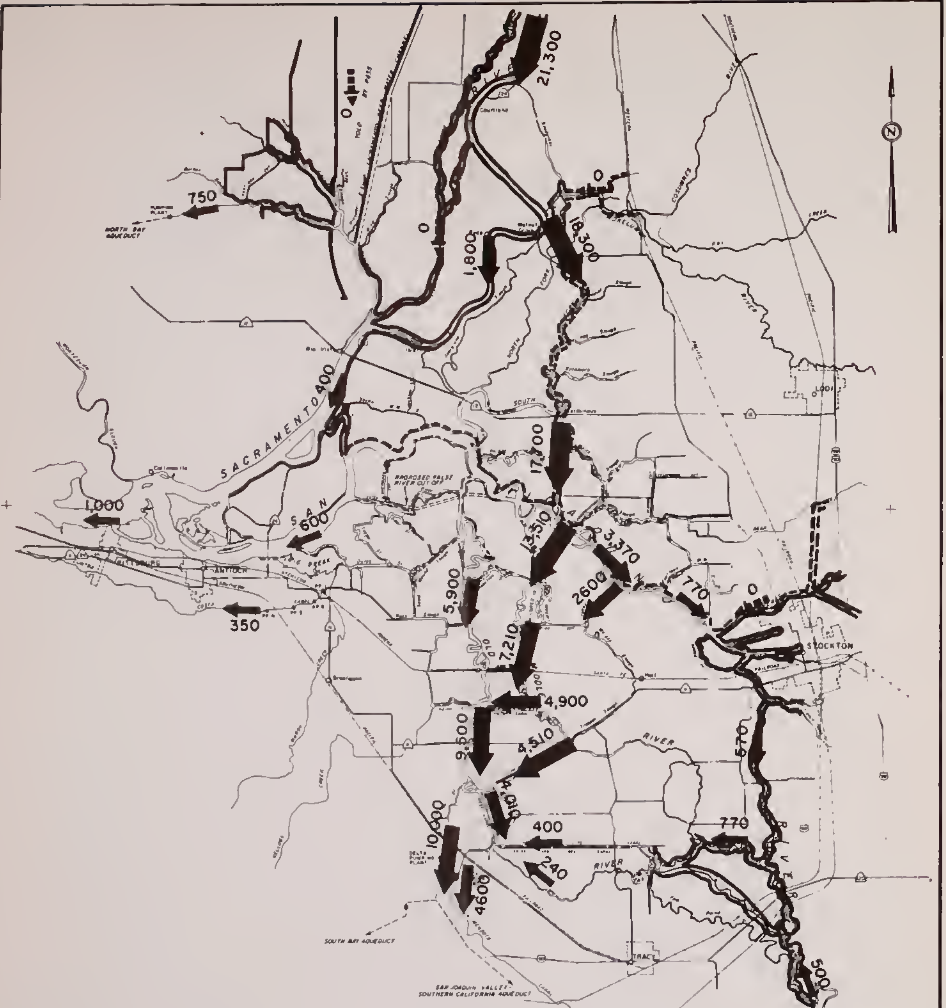
DELTA BRANCH

TYPICAL ALTERNATIVE DELTA WATER PROJECT

APRIL 1962



LEGEND

5,000 ➡	FLOW IN CUBIC FEET PER SECOND
———	EXISTING LEVEES
— — —	PROJECT LEVEES

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TYPICAL ALTERNATIVE DELTA WATER PROJECT SUMMER FLOW DISTRIBUTION

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SCALE IN MILES
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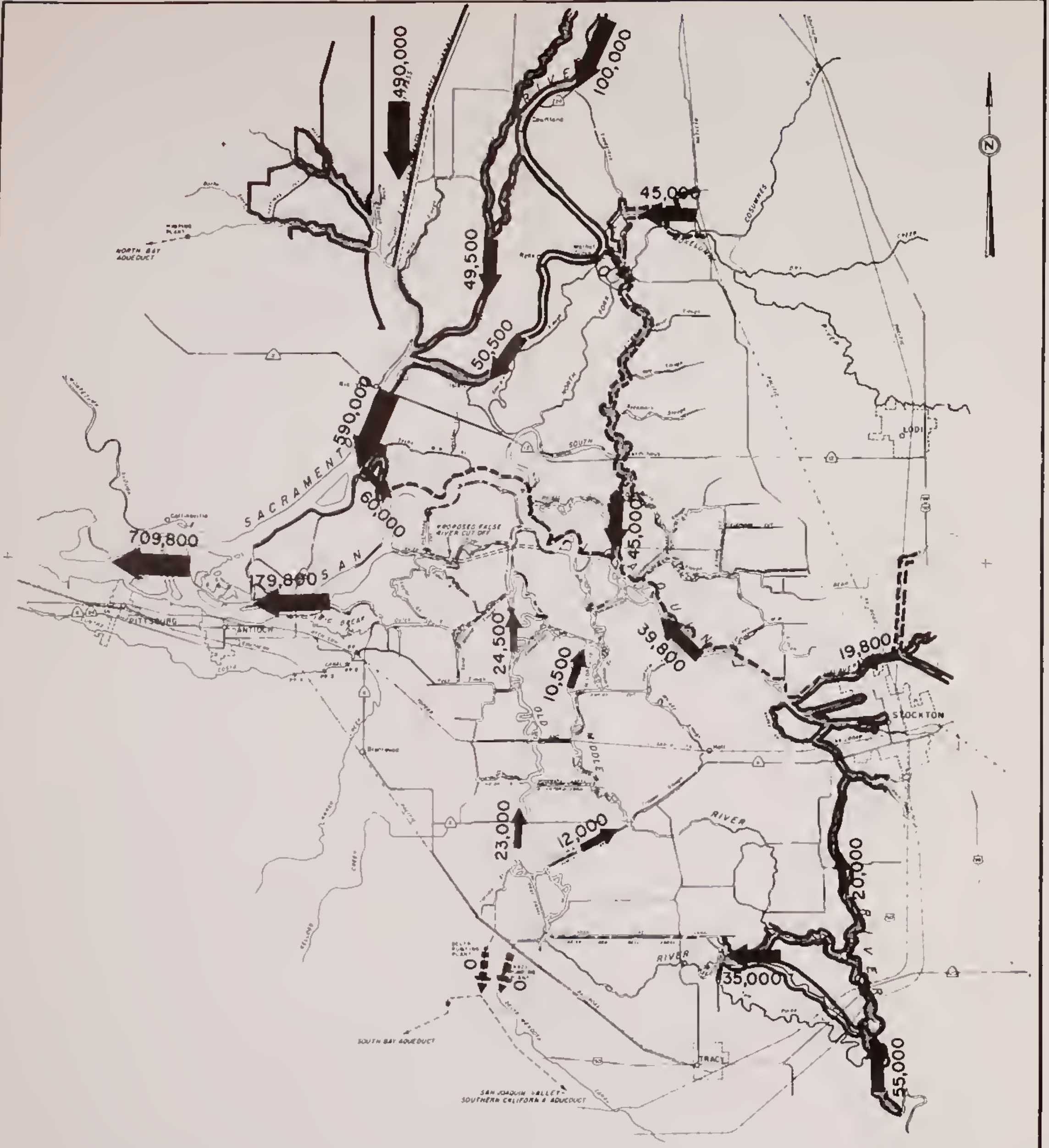

LEGEND

5,000 ➡ FLOW IN CUBIC FEET PER SECOND

——— EXISTING LEVEES

- - - - - PROJECT LEVEES

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TYPICAL ALTERNATIVE DELTA WATER PROJECT WINTER FLOW DISTRIBUTION

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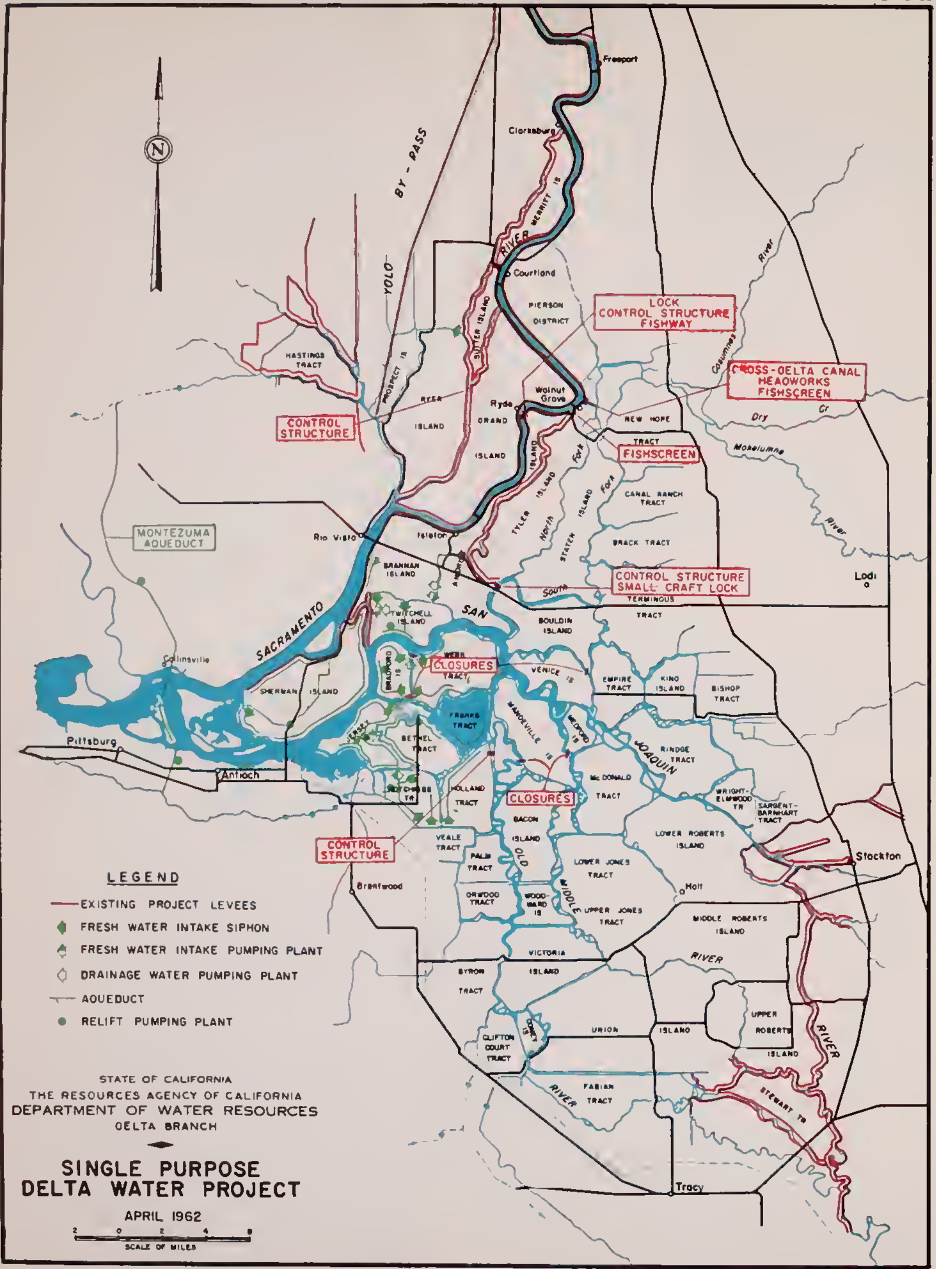
SCALE IN MILES
2 0 2 4 6

PLATE 35



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SINGLE PURPOSE DELTA WATER PROJECT

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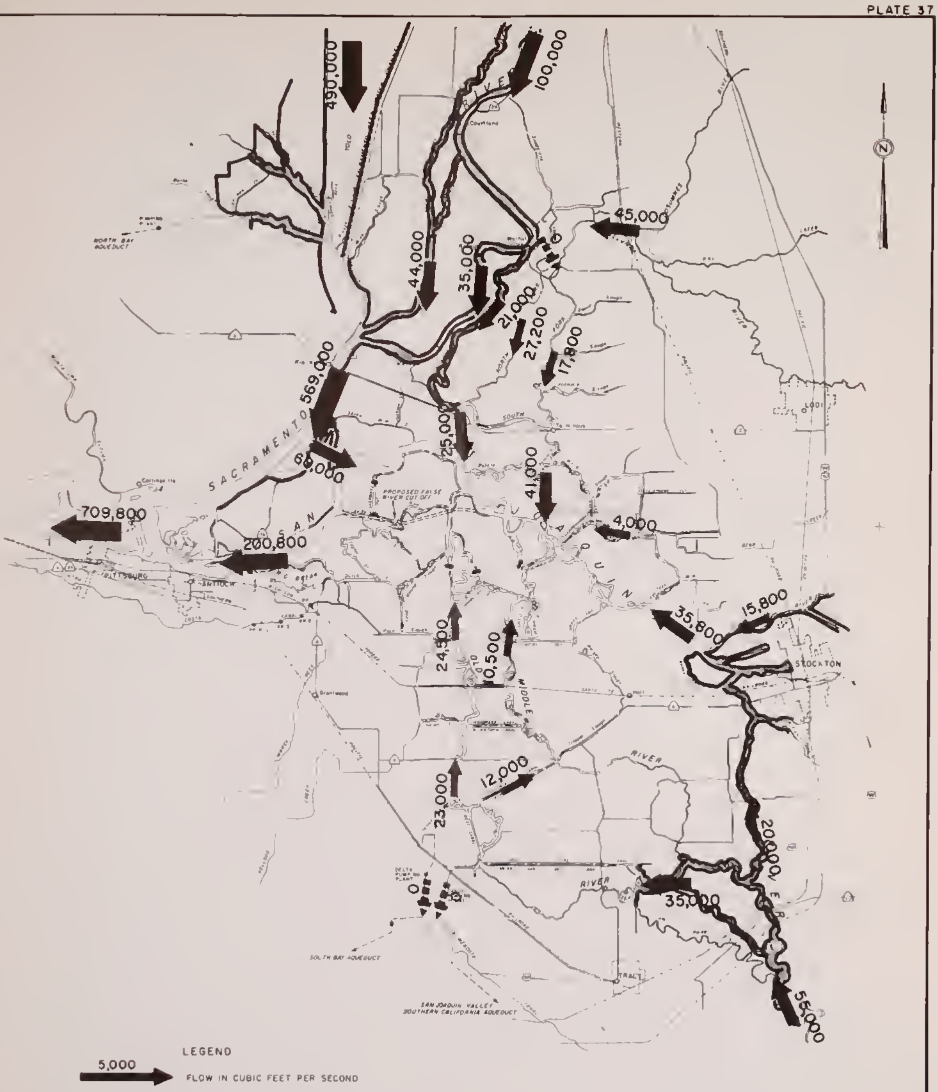

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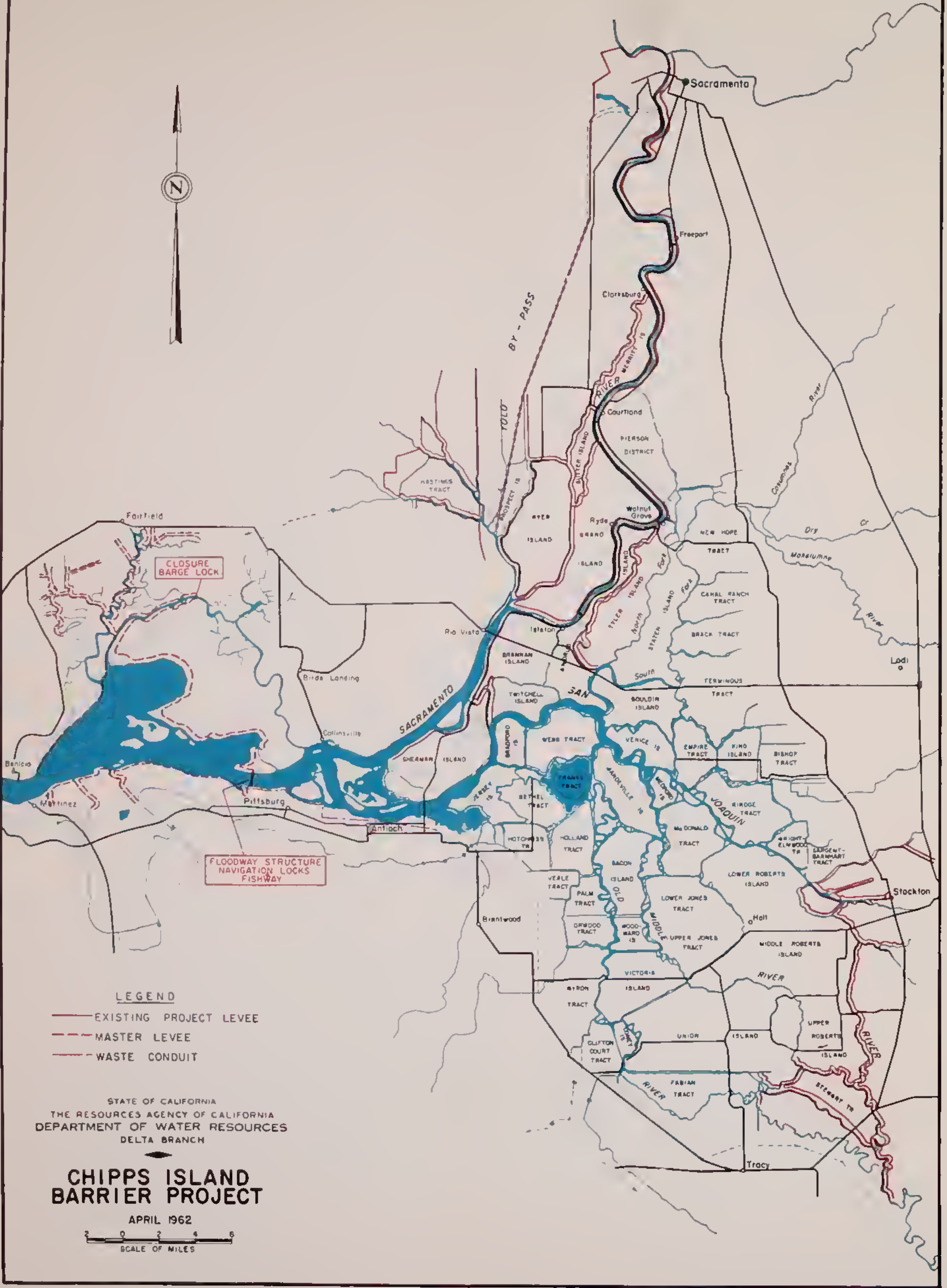
SCALE IN MILES



LEGEND

▬	EXISTING PROJECT LEVEE
‒ ‒	MASTER LEVEE
‒ · ‒	WASTE CONDUIT

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CHIPPS ISLAND BARRIER PROJECT

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2 0 2 4 6
SCALE OF MILES

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CHIPPS ISLAND
BARRIER PROJECT
SUMMER FLOW DISTRIBUTION

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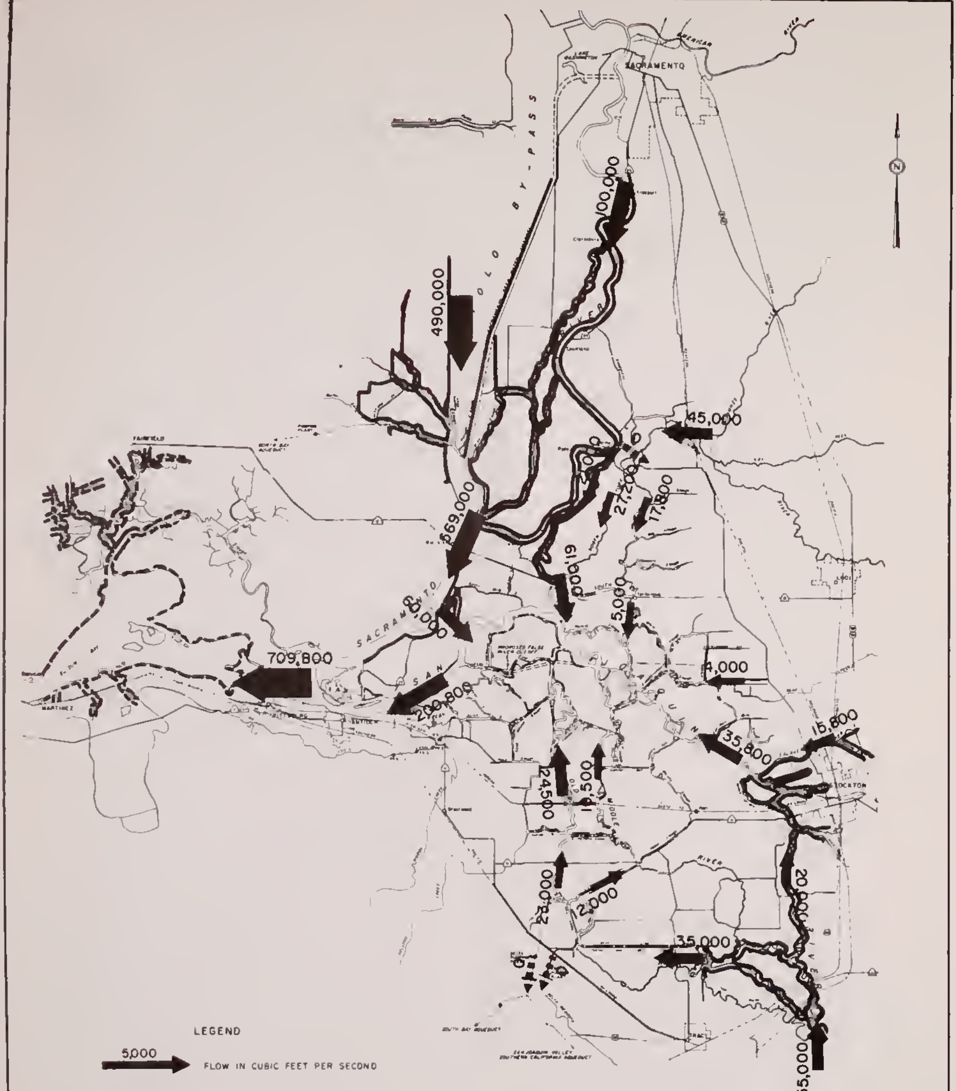
PLATE 40



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